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Wastewater Recycle and Reuse Potential for Indirect Discharge Textile Finishing Mills
Volume 1. Technical Report

Sverdrup and Parcel and Associates, Inc.
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WASTEWATER RECYCLE AND REUSE POTENTIAL FOR INDIRECT DISCHARGE TEXTILE FINISHING MILLS

Volume 1. Technical Report

by

Jon F. Bergenthal

Sverdrup & Parcel and Associates, Inc.
St. Louis, Missouri 63101

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EPA Project Officer: Robert V. Hendriks

Industrial Environmental Research Laboratory
Utilities and Industrial Processes Division
Research Triangle Park, NC 27711

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16. ABSTRACT The report gives detailed information on a variety of wastewater recycle/reuse technologies that allow textile finishing mills to reduce the volume of wastewater and the amount of pollutants discharged to publicly owned treatment works. (NOTE: Dyebath reconstitution is described separately.) Many of these technologies have been demonstrated full-scale, but only a few have become widely applied in the textile industry. Technical and economic factors affect the application of most of these technologies at a given mill; thus, each must be considered under its own mill-specific conditions. Included for each described technology are a description, its environmental benefits, recycle and treatment system schematics, design criteria, technical factors that limit or enhance its application, capital and yearly costs, factors that affect its economic fasibility, its current applications, and references for further information. The information in this report is based on a survey of the literature, discussions with equipment/process vendors and researchers, and engineering studies at six textile finishing mills. The six mills provide a good cross-section of the variety of products, fibers, manufacturing processes, and potential recycle/reuse technologies encountered in textile finishing. Volume 2 of the report consists of the six mill engineering reports.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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Textile Finishing	Stationary Sources	13H
Waste Water	Recycling	
Circulation		14G
Waste Treatment		

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ABSTRACT

Over 80 percent of textile finishing mills discharge their wastewater to publicly owned treatment works. The majority of the wastewater receives little or no pretreatment before discharge into municipal collection systems. A variety of wastewater recycle/reuse technologies have been developed to allow these mills to reduce the volume of wastewater and the amount of pollutants discharged.

Many of these technologies have been demonstrated full-scale, but only a few have become widely applied in the textile industry. With most of these technolgies, specific technical and economic factors affect their application at a given mill, and thus each application must be considered under its own mill-specific conditions.

This report presents detailed information on each of the wastewater recycle/reuse technologies. Included for each are a description of the technology, its environmental benefits, recycle system and treatment system schematics, design criteria, a discussion of technical factors that limit or enhance the application of this technology, capital and yearly costs, an examination of factors that affect the economic feasibility of the technology, listings of current applications of the technology, and references for further information.

The recycle/reuse technology information in this report is based on a survey of the literature, discussions with equipment/process vendors and researchers, and engineering studies conducted at six textile finishing mills. These six mills provide a good cross-section of the variety of products, fibers, manufacturing processes, and potential recycle/reuse technologies encountered in textile finishing. They were selected from a larger group of mills that had been identified as good candidates for investigating and adopting wastewater recycle measures. The six mill engineering reports appear as Volume 2 of this report.

This report is submitted in accordance with Contract Number 68-02-3678 between the U.S. Environmental Protection Agency and Sverdrup & Parcel and Associates, Inc. It documents the work performed under Phases I and II of the contract. A future report will cover a detailed investigation of dyebath reconstitution under Phase III of the contract.

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UNIT CONVERSION TABLE

Flow/Volume

1 gallon = 0.003785 m^3
1 gpm (gallon per minute) = 6.308×10^{-5} m^3/s
1 mgd (10^6 gallon/day) = 0.0438 m^3/s

Mass

1 lb = 0.4536 kg
1 ton = 907.2 kg

Length

1 foot = 0.3048 m
1 yard = 0.9144 m

Velocity

1 ft/sec = 0.3048 m/s

Pressure

1 psi (lb/in^2) = 6.895 kPa (kN/m^2)

Energy, Power

1 Btu = 1.055 kJ
1 Btu/day = 0.0122 W(J/s)
1 HP (horsepower) = 0.7457 kW
1 ton (cooling) = 3.514 kW

Temperature

°F = °C x 9/5 + 32
°C = [°F - 32] x 5/9

Miscellaneous

1 gal/lb = 0.00834 m^3/kg
2 gal/ft^2-day = 0.04074 m^3/m^2-day
1 Btu/hr-ft^2-°F = 5.678 J/s-m^2-°C

SECTION I
INTRODUCTION

Approximately four million tons (3.6×10^9 kg)* of textile products are finished annually in the United States. About 2,000 finishing mills are involved in this production, and annually discharge in excess of 100 billion gallons of wastewater. The majority of water use and wastewater discharge in the textile industry occurs in the following four industry sectors:

- Woven fabric finishing
- Knit fabric and hosiery finishing
- Carpet finishing
- Stock and yarn finishing

A survey of over 1,000 finishing mills in the textile industry was recently conducted for the Effluent Guidelines Division of EPA. As shown on Table I-1, the results indicate that 81 percent of the surveyed mills in these industry sectors discharge their wastewater to publicly owned treatment works (POTW). The amount of wastewater produced by these indirect discharge mills is estimated to exceed 210 mgd. The survey further demonstrates that much of this wastewater receives either no treatment (58 percent of mills) or only preliminary treatment (33 percent of mills) prior to discharge. Preliminary treatment includes any of the following operations: gross solids removal by settling or screening, equalization, and neutralization.

Because of the significant total volume of wastewater discharged to POTWs by textile mills, the Office of Research and Development, in support of the Effluent Guidelines Division, is evaluating textile mill wastewater recycle and reuse as a means of reducing water consumption and wastewater discharge rates.

In addition to the benefits of reduced water consumption and wastewater discharge, recycle and reuse can result in significant economic benefits to an indirect discharge textile mill from savings in

---

* The units of measurement most familiar to the projected readership of this report have been maintained.

TABLE I-1

METHOD OF WASTEWATER DISCHARGE IN SELECTED TEXTILE INDUSTRY SECTORS

Industry Sector	No. of Mills in Survey Base	Percentage of Base with Discharge Type		
		Indirect	Direct	None*
Woven Fabric	311	73	25	2
Knit Fabric	268	83	14	3
Hosiery	161	94	4	2
Carpet	55	76	20	4
Stock and Yarn	211	82	17	1
Total	1,006	81	17	2

* Includes such disposal methods as land application and evaporation.

water costs, sewer use fees, end-of-pipe pretreatment costs, energy, and chemicals. Therefore, strong incentives for implementing wastewater recycle and reuse exist even in the absence of pretreatment regulations.

Many textile manufacturing processes have been identified in recent years as being suitable for the application of wastewater recycle or reuse. Various technologies have been investigated for these applications in tests ranging from bench-scale to full-scale demonstrations. Nevertheless, the application of recycle and reuse in textile mills remains rather limited. Only a few recycle technologies, such as caustic recovery from mercerizing washwater, and direct in-process water reuse by countercurrent washing, have been adopted by a relatively large number of mills. Most other recycle technologies have been adopted by only a few mills.

Several reasons for the limited use of recycle in the textile industry can be cited:

- Lack of specific technical knowledge about available recycle/reuse technologies, the benefits and limitations of these technologies, and application of this information in performing a feasibility study.
- Concerns about the cost effectiveness of wastewater recycle (capital cost vs. return on investment).
- Competing areas for capital expenditures in the mill.
- Concerns about site-specific factors that could limit the applicability or cost effectiveness of recycle technologies.

The goal of this project is to provide information that defines the applicability of recycle/reuse in the textile industry. This is done by performing the following tasks, grouped by project phase.

Phase I

1. Identifying applicable recycle/reuse technologies and gathering available information on those technologies to define areas for potential application, benefits, limitations, and approximate cost data.

2. Identifying a group of textile mills that appears to have high potential for applying recycle/reuse technologies.
3. Selecting six representative mills from this group to participate in actual field studies of the applicability of wastewater recycle/reuse measures under Phase II.

Phase II

1. Visiting the six mills to collect information on textile processing, machinery, fiber and chemical use, energy and water use, and wastewater discharge and characteristics.
2. Performing a technical evaluation of the feasibility of employing various recycle/reuse technologies at the six mills. This work includes bench-scale testing of the technologies when appropriate.
3. Performing an economic evaluation of technically feasible technologies to define capital costs, operating costs, and textile production savings.

Phase III

1. Selecting one or more recycle technologies that have technical and economic promise for more wide-spread use.
2. Performing lab- and full-scale developmental work with these technologies at a textile mill.
3. Preparing a detailed manual covering the investigations and application of the technologies.

This report presents the results of the first two project phases. Conclusions from Phases I and II are given in Section II of this report. A separate report will be issued detailing the third phase of the project.

Section III of this report presents a brief introduction to textile manufacturing processing and the resulting wastewater from these operations.

Section IV presents a listing of recycle/reuse technologies available in the textile industry and defines where these technologies are applicable. An evaluation of the potential for expanded use of these technologies in the textile industry is also presented.

Section V examines the number of indirect discharge textile mills that are potential candidates for employing these various recycle/reuse technologies.

Sections VI to XIV provide detailed information on individual recycle/reuse technologies, including a description of each technology, flow schematics, environmental benefits, production benefits, technical limitations, and cost information.

The six mill studies conducted under Phase II of the project are presented in Volume 2 of this report.

SECTION II
CONCLUSIONS

Many wastewater recycle/reuse technologies have been identified as being applicable to textile finishing mills:

- Direct recycle/reuse (no treatment)
- Reconstitution and reuse
- Separation and reuse by filtration
- Separation and reuse by membrane separation processes
- Separation and reuse by precipitation
- Separation and reuse by evaporation
- Separation and reuse by coagulation/flotation
- Separation and reuse by carbon or exchange resin adsorption
- Chemical oxidation and reuse.

These technologies can offer significant environmental benefits (reduced wastewater and pollutant discharge) as well as significant cost savings to textile finishing mills (lower water and sewer fees, and reduced chemical and energy usage).

A survey of 367 indirect discharge textile finishing mills indicated that 40 percent were good candidates for applying recycle/reuse technologies. And many of the smaller mills that were not considered as good candidates for capital intensive recycle technologies may still be able to apply less costly direct reuse technologies.

Textile mills will implement these recycle technologies only if they are both technically feasible and economically justified. Technologies such as direct reuse (e.g., countercurrent rinsing, cross-process reuse of wash water, and reconstitution and reuse of bleach or dyebaths) are inexpensive to institute and are thus generally cost-effective.

Several other technologies employ separation technologies to recover valuable processing chemicals and recycle water. This group of technologies includes size recovery by ultrafiltration, caustic recovery by evaporation, and dyestuff recovery by ultra- or hyperfiltration. The value of the recovered chemical can be sufficient to make these technologies economically attractive to the textile industry. In certain cases, chemical or dye reuse may not be possible or cost effective due to complex finishing procedures or product quality demands.

Other recycle/reuse technologies are technically feasible but the cost savings are not high enough to justify their use by many mills. Examples are treatment and reuse of dye wastewater by activated carbon or oxidation, and treatment and reuse of printing wastewater by coagulation. These recycle technologies do have promise when special circumstances such as pretreatment requirements or limited water supplies alter the economics of treatment and reuse.

Several technologies are still in the developmental stage. These include exchange resin treatment of dye wastewaters to allow dye recovery and/or water reuse, and thermal precipitation and recovery of special sizing compounds.

The six mills selected for evaluating the applicability of these technologies exhibited a variety of recycle/reuse needs. At some mills, only a single processing step was amenable to wastewater recycle. At other mills, recycle had potential in several areas. Such variety is expected throughout the industry, with some mills not able to employ wastewater recycle at all.

The evaluation of recycle at a given mill is a complex process requiring much preliminary evaluation and testing to ensure its applicability. Aspects such as the following must be considered:

- Process mass balances
- Need for and ability to reuse recovered materials or water
- Effects of recycle on product quality, capacity, and equipment
- Space availability
- Recycle/reuse economics

Full-scale testing is often needed to adequately address these areas. Finally, modifications in production procedures are sometimes required to implement or optimize recycle. These range from better control of process flows and better housekeeping to modifying production schedules or reformulating dye recipes. All these factors point to the need to carefully evaluate recycle/reuse applications in the textile finishing industry.

SECTION III

TEXTILE INDUSTRY MANUFACTURING PROCESS AND WASTEWATER DESCRIPTIONS

The textile manufacturing industry is generally categorized by the end product of manufacture. Woven fabrics, knit fabrics, carpet, and stock/yarn are four major end products in the industry. About 90 percent of the U.S. textile finishing mills can be classed in these four sectors. Other types of end products, such as nonwoven fabrics, felted fabrics, scoured wool, and others account for the remaining 10 percent of finishing mills. In addition, a sizeable number of mills are engaged in the manufacture of greige, or unfinished, fabrics. These mills, however, generally produce little or no process wastewater.

A description of the end products, fibers, and manufacturing processes encountered in each of the four major sectors is presented below. General wastewater characteristics are noted for each process. These wastewater characteristics are dependent not only on the product and fiber type, but are determined to a large extent by the type of processing, i.e., batch versus continuous, used. Consequently, the choice of wastewater recycle/reuse technologies is often dependent on whether batch or continuous processing is employed.

In continuous processing, the textile material is generally passed through a saturator or pad box wherein it contacts with the process chemicals (dyes, caustic, bleach, etc.). A steamer or J-box usually follows to allow for the appropriate contact time. Several wash boxes then follow wherein excess chemicals are rinsed from the product. A relatively dilute wastewater results from the wash boxes.

In batch processing, the textile material is contacted with the process chemicals in a tank (kier, beck). Following the required contact time, the exhausted process chemicals are dropped and the tank is filled with water to rinse the product and remove excess chemicals. Therefore, a relatively concentrated wastewater results from the initial drop, followed by less concentrated rinse water drops.

WOVEN FABRIC FINISHING

Typical end products in the woven fabric finishing sector of the textile industry include sheeting, apparel fabric, towels, upholstery fabric, and various industrial fabrics, among others. Due to the diversity of end products in this sector, a wide variety of fibers are used in their manufacture. The most common fiber types are cotton-polyester blends and 100 percent cotton. Other fiber types include polyester, rayon, acetate, acrylic, nylon, and various blends of these fibers.

Figure III-1 represents a typical production schematic for woven fabric finishing mills. The various production processes are described below. Both batch and continuous processing are commonplace in this sector of the industry, with most large production mills employing continuous processing equipment.

Desizing

Prior to the weaving of greige fabric, a sizing compound is usually applied to the warp (lengthwise) yarns. The purpose of the size is to impart tensile strength and smoothness to the warp yarns and thereby decrease yarn breakage during weaving. The sizing compound may represent up to 15 percent of the final weight of the greige fabric, although 5 to 10 percent is a more typical range.

Historically, starch was the primary size used in the weaving of cotton fabric. More recently, synthetic sizes such as polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), polyacrylic acid (PAA), and polyester-based sizes, as well as chemically modified starches have been introduced. Starch is still the major size used, but the increasing use of synthetic fibers, filament yarns, and shuttleless looms has created greater demand for different sizing compounds. Other ingredients, such as lubricants, preservatives, softeners, and fillers are also included in the sizing compound applied to the warp yarns.

The purpose of desizing at the finishing mill is to remove the size added at the weaving mill. Starch, typically used on cotton fabrics or cotton-polyester blends (PVA-starch mixtures), must be partially hydrolized by acid or enzymes to make it water soluble. The

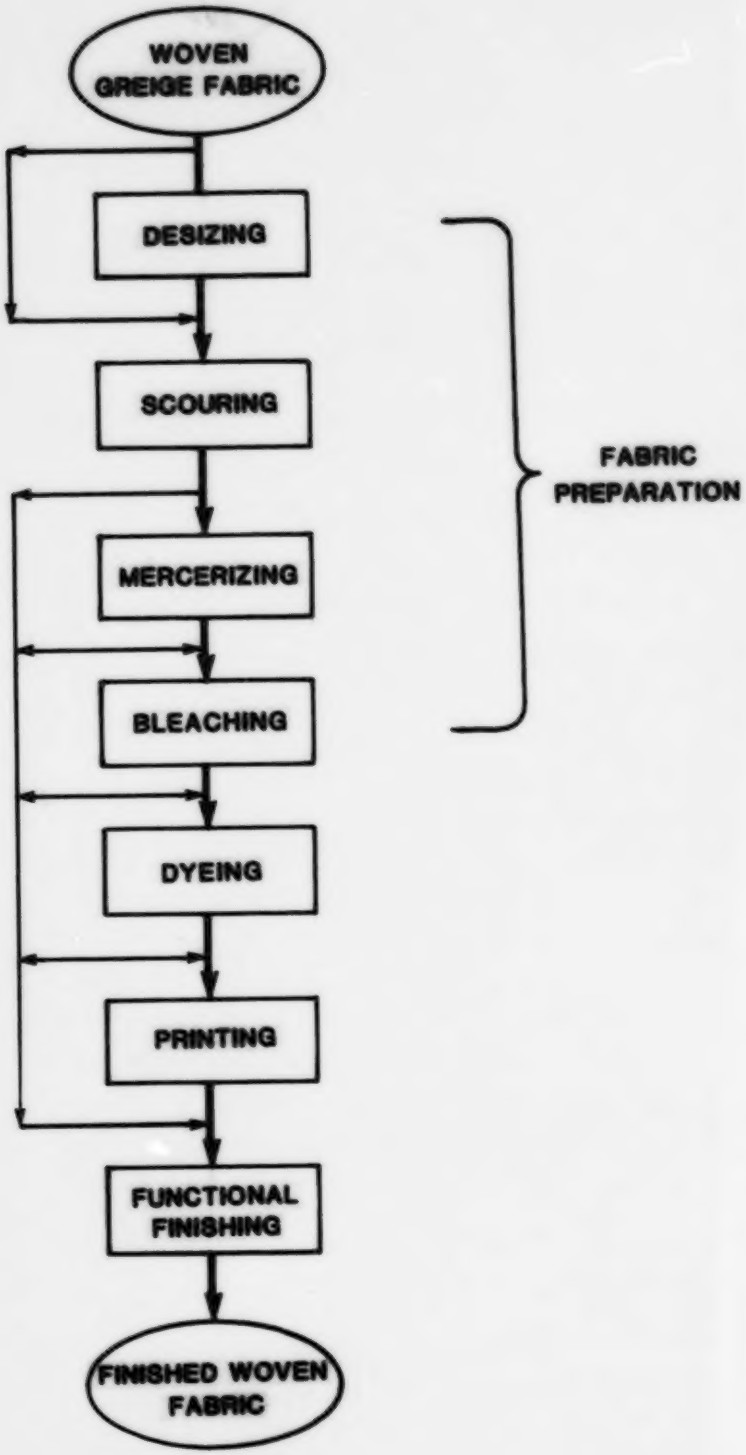

WOVEN GREIGE FABRIC
DESIZING
SCOURING
MERCERIZING
BLEACHING
DYEING
PRINTING
FUNCTIONAL FINISHING
FINISHED WOVEN FABRIC
FABRIC PREPARATION

FIGURE III-1
TYPICAL WOVEN FABRIC FINISHING SCHEMATIC

solubilized starch is then removed with hot water washing. PVA and CMC, typically used with synthetic fibers and blends, are soluble in hot water and are therefore removed with hot water washing. Acrylic and polyester-based sizes, typically used with filament yarns, are removed with a hot, alkaline scour. Partial degradation of the size occurs under these hot, alkaline conditions. Hot water washing follows the scour. The wastewater generated from desizing is therefore hot and contains significant quantities of organics in the form of sizing materials removed from the fabric. This wastewater stream can account for half or more of a finishing mill's organic pollutant load.

Scouring

Scouring is used to remove additional impurities from textile fibers prior to coloring and functional finishing operations. Natural fibers, such as cotton, contain significant amounts of impurities, such as oils and waxes, that are removed by scouring with hot alkaline (2 percent caustic) or soap solutions. Synthetic fibers, by comparison, are relatively free of impurities and require only a light scour with mild detergents. In both cases, hot water washing follows the scour.

Scouring wastewater characteristics therefore depend on the type of fiber being processed. Wastewater from cotton scouring is hot, alkaline, and generally has a very dark color from the removed fiber impurities. Wastewater from synthetic fiber scouring is hot and contains much fewer impurities.

Mercerizing

Cotton fibers may be treated with caustic (sodium hydroxide) to increase fiber tensile strength, luster, sheen, dye affinity, and abrasion resistance. Mercerization consists of contacting the fibers with a cold, 15 to 30 percent caustic solution for the desired contact period, followed by hot water washing to remove residual caustic from the fibers.

The wastewater (washwater) from mercerizing is hot and alkaline, containing one to five percent sodium hydroxide, but contains relatively few fiber impurities since most impurities have already been removed from the fibers in upstream processes.

Bleaching

Bleaching is performed to remove natural coloring from cotton and cellulosic fibers (acetate and rayon) prior to coloring or other finishing steps. Hydrogen peroxide is a common bleaching agent, although other oxidizing or reducing compounds such as hypochlorite and perborates may be used.

Whitening of synthetic fibers is sometimes performed using weak bleaches or optical whitening agents. Hot water washing follows bleaching to remove unreacted bleaching chemicals and byproducts.

The wastewater from bleaching is hot and contains the unreacted bleaching compounds and by-products removed during the washing step.

Dyeing

The dyeing process is used to anchor dyestuff molecules to the textile fibers, thereby imparting color to the textile product. The fiber type and final product requirements (e.g., color, wet-fastness) both influence the selection of the dyestuff to be used. The most common classes of dyestuffs are listed below. Washing or rinsing generally follows dyeing to remove excess dye and auxiliary chemicals.

- Acid - Acid dyes are used primarily on nylon and wool fibers. They are generally applied from a dyebath containing the dye, salt (sodium chloride or sodium sulfate), acid (acetic, sulfuric, or formic), retarding and leveling agents, and other auxiliary chemicals.

- Basic - Basic dyes are used primarily on acrylic fibers. They are generally applied from a dyebath containing the dye, salt, acid, retarding and leveling agents, and other auxiliary chemicals.

- Direct - Direct dyes are used primarily on cellulosic fibers, e.g., cotton. They are generally applied from a dyebath containing the dye, salt, wetting, sequestering, and leveling agents, and other auxiliary chemicals.

- Disperse - Disperse dyes are used primarily on polyester and other synthetic fibers. They are generally applied from a dyebath containing the dye, a dispersing agent, dye carriers, and other auxiliary chemicals.

- Vat and Sulfur - Both vat and sulfur dyes are used primarily for dyeing cellulosic fibers. They are generally applied in a reduced form from a dyebath containing the dye, salt, a reducing agent, and a base (caustic or soda ash). Following dye application, the dye is oxidized to an insoluble form either by exposure to air (typical for vat dyes), or with an oxidizing chemical such as peroxide or perborate.

- Reactive - Reactive dyes are used primarily for dyeing cellulosic fibers. They are generally applied from a dyebath containing the dye, salt, and other auxiliary chemicals. An alkaline fixing bath (sodium carbonate) is then used to fix the fiber-dye bonds.

Wastewater from dyeing contains unexhausted dyes (typically about five percent of the amount of dye added) and the auxiliary chemicals used in the dyeing process. Thus, dyeing wastewaters are highly colored and contain significant concentrations of organics (dyes and auxiliaries) and inorganic salts (auxiliaries).

Printing

Printing is used to apply color to specific selected areas of the fabric. Pigments or dyestuffs are transferred to the fabric either by screen printing or engraved roller printing. The fabric may then be set or aged (steamed), and washed to remove excess dyes and pigments.

Wastewater from fabric washing is hot, contains some color from excess dyes and pigments, and generally contains a surface active agent (soap) used in the washing process. A large quantity of wastewater is also generated from equipment washdown. This wastewater contains large amounts of color, suspended solids, and solvents used in the printing formulations and removed during the cleaning of printing rollers and belts.

Functional Finishing

Functional finishes (e.g., water repellants, permanent press, flame resistance, etc.) are generally padded onto the fabric which is then dried and cured. A small amount of wastewater is generated from equipment washdown.

KNIT FABRIC FINISHING

Typical end products in the knit fabric finishing sector of the textile industry include men's and ladies' hosiery, under- and outerwear, and miscellaneous household and industrial items.

Nylon is the primary fiber used in ladies' hosiery manufacture, along with a smaller amount of polyester. The predominant fibers in men's hosiery production are acrylic, nylon, and cotton. Knit fabrics for under- and outerwear are most commonly produced from polyester yarns, with smaller amounts of cotton, nylon, acetate, and acrylic in use.

Figure III-2 represents a typical production schematic for knit fabric finishing mills. Finishing of hosiery is generally a simpler operation and is shown in a separate schematic. For a description of knit fabric processing operations, refer to the descriptions of manufacturing processes under "Woven Fabric Finishing." The only difference of significance is that scouring of knit fabrics will remove oils applied to the yarns during knitting of the greige fabric. Note that desizing and mercerizing are not performed in this sector of the textile industry and that synthetic fibers are the predominant fibers used. Batch processing is almost exclusively used in this sector of the industry.

CARPET FINISHING

The vast majority of carpeting produced for domestic and commercial markets consists of nylon yarns tufted into a jute or polypropylene backing. A small quantity of polyester and acrylic carpeting is also produced. Mills that pre-dye carpet yarns before the tufting operation are generally classified as stock/yarn finishing mills and are discussed later. Mills that employ greige yarns in tufting and perform dyeing or printing of the carpet are discussed herein. Figure III-3 represents a typical production schematic for carpet mills.

The actual tufting operation is a dry operation, i.e., no water is used in the process. Carpet yarn is fed to a bank of hundreds of needles that pull or loop the yarn through the backing material. The loops may also be cut or sheared to produce cut pile carpeting.

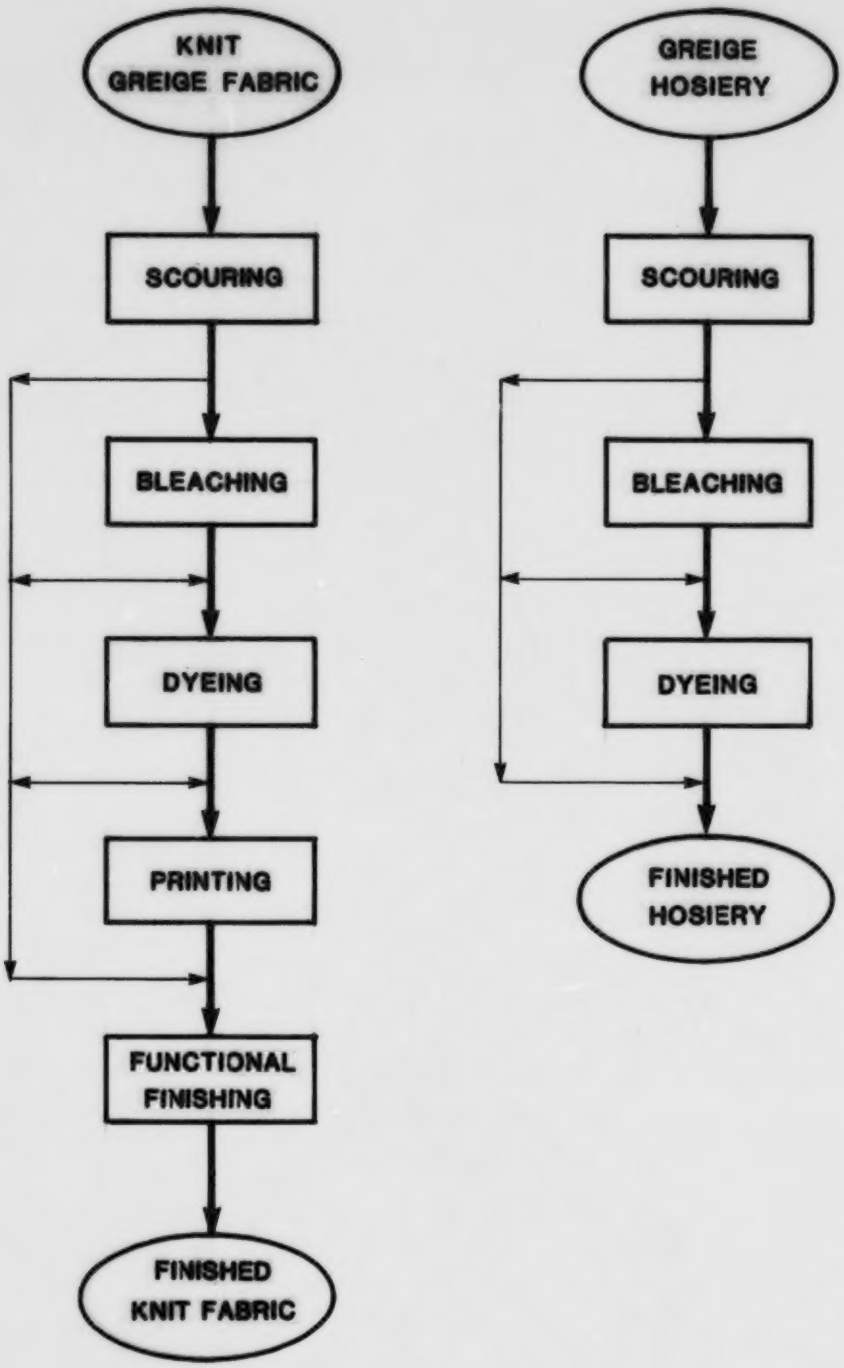

KNIT GREIGE FABRIC
SCOURING
BLEACHING
DYEING
PRINTING
FUNCTIONAL FINISHING
FINISHED KNIT FABRIC
GREIGE HOSIERY
SCOURING
BLEACHING
DYEING
FINISHED HOSIERY

FIGURE III-2
TYPICAL KNIT FABRIC AND HOSIERY FINISHING SCHEMATIC

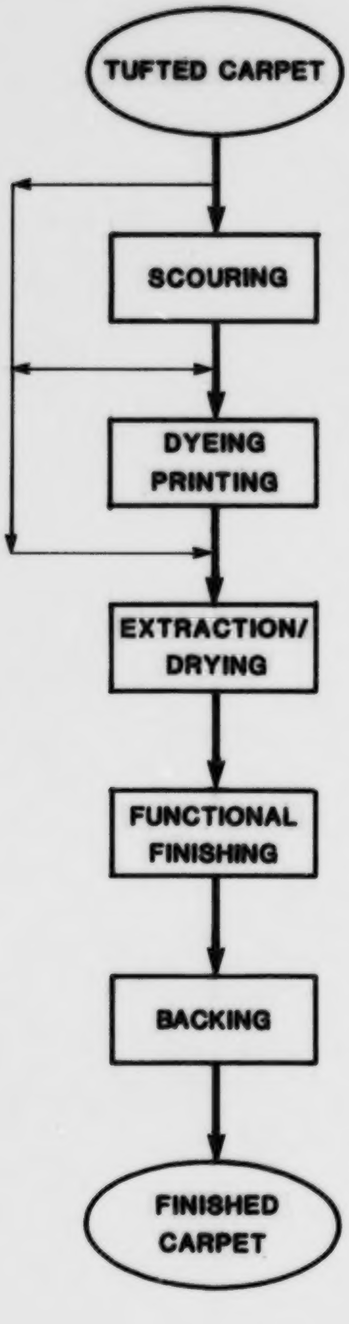

TUFTED CARPET
SCOURING
DYEING
PRINTING
EXTRACTION/
DRYING
FUNCTIONAL
FINISHING
BACKING
FINISHED
CARPET

FIGURE III-3
TYPICAL CARPET FINISHING SCHEMATIC

Scouring of the carpet is similar to the process described previously for synthetic fibers.

Dyeing may be either batch or continuous. Acid dyes are the predominant dyestuff used for dyeing nylon, although some disperse dyes are also used. Basic dyes are generally used for acrylic yarns and disperse dyes for polyester. Batch dyeing is performed in a large beck, usually at atmospheric pressure. High liquor:carpet ratios are needed in batch dyeing due to the bulk of the carpet involved. Continuous dyeing/printing can also be performed to color the carpet face yarns.

Excess dye rinsewater is removed from the carpet by vacuum extraction. This minimizes the energy required for carpet drying.

Following drying, a secondary backing is applied to the carpet. Latex is generally used to laminate the secondary jute or polypropylene backing to the carpet. Some carpets have a urethane or latex foam backing applied instead.

Functional finishes, such as soil retarders and flame and mildew retarders, are sometimes applied to the finished carpet.

STOCK/YARN FINISHING

Woven fabric, knit fabric, and carpet can all be produced using finished yarn rather than greige yarn. In addition, finished yarn and stock are themselves final products. Mills that produce finished stock and yarn are described herein.

Due to the wide variety of final products from yarn, all fiber types are represented in this industry sector. The predominant fibers are cotton, polyester, acrylic, and nylon.

Figure III-4 depicts the typical sequence of manufacturing processes involved in stock and yarn finishing. The details of these processes have been previously discussed.

Most of the processing in this industry sector is batch, or package, processing. Cones or packages of yarn are loaded into the dye machine and proceed through the various scouring, bleaching, and dyeing operations. Batch skein dyeing for yarn and batch dyeing of loose stock are also performed.

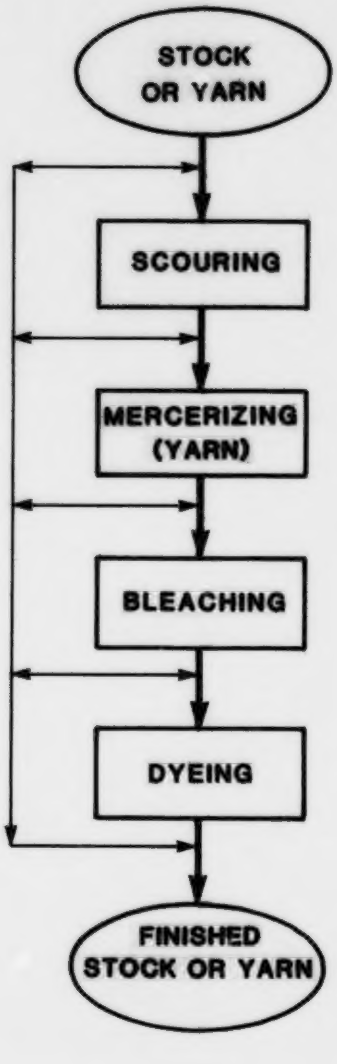

STOCK OR YARN
SCOURING
MERCERIZING (YARN)
BLEACHING
DYEING
FINISHED STOCK OR YARN

FIGURE III-4
TYPICAL STOCK AND YARN FINISHING SCHEMATIC

A smaller amount of yarn is dyed on continuous ranges. Examples are indigo or slasher dyeing for denim warp yarns, space dyeing used for some carpet yarns, and knit-deknit dyeing in which yarn is knit into a tube, dyed on a continuous range, set, and deknit to produce a textured yarn.

SUMMARY OF WASTEWATER CHARACTERISTICS

Table III-1 presents a summary of typical or average wastewater characteristics for the various production processes discussed above. Values are given per 1,000 pounds of product. These are presented only to give the reader a rough comparison of the relative strengths and volumes of wastes typically generated in textile processing. The evaluation of application of wastewater recycle and reuse technologies must, of course, be based on mill specific waste stream characterizations. The specific liquor ratios used in processing at a given mill, along with the specific processing chemicals, dyestuffs, and fibers processed, will all affect the actual wastewater characterization and the choice of appropriate wastewater recycle/reuse technologies.

TABLE III-1
TEXTILE WASTEWATER CHARACTERIZATION

Process	Wastewater Flow (gal/1,000 lb)	BOD (lb/1,000 lb)	TSS (lb/1,000 lb)
Desizing			
Starch Size	1,500	46	89
Synthetic Size	1,500	2-4*	5
Scouring			
Cotton	3,000	21	5
Cotton/Poly	3,000	11	5
Synthetics (see Scour/Dye)			
Mercerizing	2,000	4	5
Bleaching	2,000	1	4
Dyeing	5,000	3-24	--
Scour/Dye			
Knit Fabric	8,000-16,000	22-28	7
Carpet	5,600	25	5
Stock/Yarn	12,000	21	5

Source: U.S. EPA, Development Document for Proposed Effluent Limitation Guidelines, Textile Mills, 1979.

U.S. EPA, Environmental Pollution Control - Textile Processing Industry, 1978.

*While the five-day BOD of synthetic sizes such as PVA and CMC is much lower than that of starch, the COD of the synthetic sizes is comparable to that of starch.

SECTION IV

SURVEY OF POTENTIAL WASTEWATER RECYCLE/REUSE TECHNOLOGIES

This section of the report reviews the applicability of wastewater recycle/reuse for each of the textile production operations covered in the previous section. The potential for recycle/reuse is addressed; the type of treatment required, if any, is noted; available technologies are listed; a summary assessment of the technical and economic feasibility of the technologies is made; and an assessment of the potential for increased use of the technologies within the textile industry is made. Figure IV-1 summarizes this information in a matrix form. More detailed information on individual technologies is contained in Sections VI to XIV.

Many different types of recycle/reuse technologies can potentially be applied in textile finishing mills:

- Direct recycle/reuse (no treatment)
- Reconstitution and reuse
- Separation and reuse by filtration
- Separation and reuse by membrane separation processes
- Separation and reuse by precipitation
- Separation and reuse by evaporation
- Separation and reuse by coagulation/flotation
- Separation and reuse by carbon or exchange resin adsorption
- Chemical oxidation and reuse.

Potential applications of these technologies in various textile finishing steps are addressed below.

DRY AND LOW WATER-USE PROCESSES

Dry operations include weaving, knitting, tufting, and spinning--the basic processes used in manufacturing greige textile products. No wastewater results from these operations.

Low water use operations include slashing (sizing), latex backing, and functional finishing. Wastewater is generated in cleanup operations. Little potential for recycle/reuse exists with these

Figure IV-1

Recycle/Reuse Technologies

	IN-PROCESS REUSE		CROSS-PROCESS REUSE										
Textile Process	Washwater Reuse	Reconstitution	To Desizing	To Scouring	Ultrafiltration	Hyperfiltration	Evaporation	Oxidation	Carbon Adsorption	Resin Exchange	Coagulation	Thermal Precipitation	Solvent Recovery
Desizing													
Starch	●												
PVA or CMC	●				●						●		
Other Sizes	●											●	
Scouring													
Cotton	●												
Synthetics	●		●										
Mercerizing	●		●	●			●						
Bleaching													
Cotton	●		●	●									
Synthetics	●	●	●	●									
Dyeing													
Continuous	●				●	●		●	●	●	●		
Batch	●	●			●	●		●	●	●	●		
Extraction	●												
Printing													
Cleanup	●										●		●
Soaper	●												

● Indicates Potential Application of Technology. (See Text for Further Details) operations due to the small volume of wastewater generated. Improved housekeeping measures and better cleanup practices are seen as the most viable ways for reducing the wastewater discharge from such operations.

DESIZING

As noted in Section III, wastewater from desizing contains the sizing compound that was applied to the warp yarns prior to weaving. The goal of recycle/reuse, as applied to desizing, is to separate the sizing compound from the desize wastewater. The sizing compound is then reused in slashing (sizing), and the wash water is recycled to the desizing process.

Size recovery and reuse is mandatory if this recycle technology is to be economical. Thus, the fate of the size during the desizing operations is a critical factor in deciding if recycle/reuse can be used. Starch sizes are hydrolyzed during removal and are therefore not reusable. Most polyacrylic and polyester based sizes are also partially degraded in the desizing step and are not reusable. Thus, recycle/reuse technologies are limited to sizes that do not have to be degraded to be made water soluble. These sizes include PVA, CMC, and certain modified acrylic and polyester sizes.

Available technologies to separate and recover size include thermal precipitation, coagulation, evaporation, and ultrafiltration. Thermal precipitation is limited to specially developed sizes such as hydroxypropyl cellulose (HPC) and hydroxypropyl methylcellulose (HPMC). These sizes are soluble in cool water, but precipitate in warm water. They have not yet proved to be acceptable substitutes for more traditional sizes in full-scale weaving tests. Thus, this technology has not yet advanced from the laboratory.

Coagulation is also limited to a few sizing chemicals such as CMC and some modified PVA sizes. Numerous problems have arisen with this technology. The recovered size has been shown to have only a limited capacity for reuse due to buildup of salts, fabric impurities, and oils, and has caused shedding, clinging, and loom stoppage problems in weaving tests. In addition, the supernatant has not been shown to be reusable. This technology also has not advanced from the laboratory stage.

Evaporation has been suggested for concentrating the dilute wastewater to an acceptable concentration for use in slashing. However, no research into the technical feasibility of this option is known. One cited disadvantage of an evaporation system is that low molecular weight impurities and desizing agents would remain with the sizing compound and could cause problems in weaving. In ultrafiltration systems, these low molecular weight impurities generally are removed in the permeate.

Ultrafiltration is currently the favored technology for size recovery. Several full-scale applications exist for recovering and reusing PVA sizes and recycling the permeate to the desizing process. Numerous tests have also shown the process to be applicable to CMC and modified polyacrylate sizes.

Further use of size recovery technology in the textile industry seems to hinge on a few variables:

- The use of thermal precipitation depends on whether sizing compounds can be developed that offer weaving efficiencies comparable to currently popular sizing compounds.

- The use of coagulation and evaporation are not seen as likely due to the numerous unresolved technical problems, and the existence of a proven, alternative technology (ultrafiltration).

- The major obstacle to further use of ultrafiltration for size recovery is the current practice of slashing (yarn sizing) at greige mills. Most large textile companies operate their own greige mills and can therefore exercise control over the type of sizing compounds used. The exclusive use of PVA or CMC sizing agents allows for recovery of the sizing compound. A company-controlled greige mill also provides a ready outlet for the recovered PVA or CMC size. Some large textile companies have therefore already instituted recycle systems for size recovery. The potential for expanded use of size recovery in these types of mills is high.

  Many finishing mills, however, especially smaller companies and commission finishers, obtain their greige fabric from sources outside their own company. These finishing mills have little or no direct control over the types and variability of the sizing compounds on the fabrics received. This seriously hinders the feasibility of adopting any size recovery technology. In general, sizing at greige mills is performed with fast and efficient weaving as the prime consideration rather than the potential for size recovery and reuse. The resultant mixtures of sizing compounds (especially mixtures of starch and PVA which are prevalent on cotton-polyester blends), and variability in sizing formulations hinders both size removal at the finishing mill as well as size recovery and wastewater reuse.

SCOURING

As noted in Section III, the wastewater from cotton scouring contains up to two percent sodium hydroxide (caustic) but also contains a large amount of impurities. Separation of the caustic and impurities from the wastewater to allow water reuse is possible with technologies such as evaporation or hyperfiltration. But such recycle technologies cannot be economically justified on water savings alone. Separation of the caustic from the impurities to allow caustic recovery as well as water reuse would technically be difficult and would also be very expensive.

Wastewater from the scouring of synthetic fibers contains little in the way of valuable chemicals to be recovered, but also contains much fewer impurities than cotton scouring wastes. Therefore, reuse of scouring wastewater (wash water) in the desizing process, where water quality requirements are less stringent, may be technically feasible. Further application of this technology must be done on a mill-by-mill basis after examining its feasibility.

For all fiber types, the reuse of scouring wash water in a countercurrent fashion should be considered. Numerous full-scale applications for the technology are in existence, and more widespread use of countercurrent washing can be expected due to its benefits (water and energy savings) and low capital costs.

MERCERIZING

Mercerizing wash water contains from one to five percent caustic along with a relatively small amount of fabric impurities and lint. The goal of reuse/recycle with regard to mercerizing is to recover a concentrated (30 to 40 percent) caustic solution from the wash water for reuse, and to recycle the treated wash water back to either the mercerizer washers, scouring washers, or desize washers. Again, the cross-process reuse of the treated wash water at the scour or desize washers must be evaluated on a mill-by-mill basis. Countercurrent flow is generally used in the mercerizer washers to minimize the flow of water to be treated.

Evaporation and membrane separation processes are two technologies available to concentrate the caustic from the washwater to a 30 to 40 percent concentration. Evaporation is the traditional technology used in this application at textile mills. This is in part due to its reliability and relative ease of operation. In addition, most caustic recovery systems were installed before advances in membrane technology produced membranes appropriate for caustic recovery. Only very recently have some new polyamide membranes been commercially marketed that are resistant to the pH values of 14 or greater that occur with concentrated caustic. No full-scale reverse osmosis systems for concentrating caustic to a 30 to 40 percent concentration are known.

Many, but not all, mills with large mercerizing operations have already installed multiple effect evaporators to recover caustic. In addition, the amount of textile products being mercerized has been steadily dropping due to the increased use of synthetic fibers. These two factors indicate that only a few additional applications for mercerizing caustic recovery exist in the textile industry at present.

BLEACHING

Bleaching wastewater contains unreacted bleaching chemicals along with waste by-products of the bleaching operation. Reuse/recycle technologies in this area include the countercurrent use of bleaching wash water, cross-process reuse of bleaching wash water in scour or desize washers, and reconstitution of batch bleach baths.

Numerous full-scale applications of countercurrent use of wash water exist; more widespread use can be expected due to the benefits (water and energy savings) and low capital cost of instituting this reuse technology.

Cross-process reuse of bleaching wash water in the scour or desize washers is less common and must be evaluated on a case-by-case basis before implementation. For example, unexhausted bleaching agents can react with and degrade sizes if returned to the desize washers. This would be undesirable if a size recovery system were in place. However, for many mills, the benefits of water and energy savings, and the low capital costs, suggest that more widespread application of this technology can be expected.

Bleach bath reconstitution is in rather limited use at present. More extensive use is expected due to the benefits of water and energy savings and low capital costs, but this may be limited to synthetic fiber bleaching. The bleaching of natural fibers will likely result in too many impurities in the bleach bath to allow for very many cycles of reuse.

DYEING

Dyeing wastewater contains unexhausted dyestuffs and the auxiliary chemicals used in dyeing. Several different types of recycle/reuse technologies have been developed for textile dyeing processes.

Reconstitution of batch dyebaths utilizes the unexhausted auxiliary chemicals and dyestuffs in the used dyebath. Dyes, water, and some chemicals are added to the used dyebath to permit additional cycles of dyeing.

Several other technologies also utilize the auxiliary chemicals remaining in the dyebath but remove or decolorize remaining dyestuffs prior to water reuse. These technologies include dyebath decoloring by oxidation, activated carbon adsorption, or exchange resin adsorption.

A third class of technologies attempts to recover and concentrate unexhausted dyestuffs from continuous dye range wash water. Available technologies include the membrane separation processes of hyperfiltration and ultrafiltration, and coagulation/flotation of the residual dyestuff. The treated wash water is often reusable.

In addition to these capital intensive technologies that rely on dye or chemical recovery and reuse to justify their economics, some less capital intensive recycle technologies exist. Countercurrent washing can be employed on continuous dye ranges. In batch dyeing, the final rinse water can often be reused as dyebath makeup water. In the carpet industry, water extracted from the carpet after dyeing can also be reused in the dyeing process. Cross-process reuse of dyeing wastewaters is generally not feasible if any color or significant amounts of auxiliary dyeing chemicals are present.

Reconstitution

Reconstitution has advanced from the many laboratory-scale tests conducted in the past several years to several full-scale installations. While at first it was believed that this recycle technology was limited to mills that performed much repeat dyeing, more recent experience has shown that sequences of different colors can readily be scheduled into dyebath reconstitution series. A large number of textile mills with batch dyeing operations are thus candidates for adopting this recycle technology, even if only at a few dye machines at a given mill. Dyebath reconstitution requires little capital investment, and generally has a payback period of less than one year. The major drawback is that a significant amount of time and effort must be devoted to testing the proposed reconstitution techniques at a given mill to ensure that product quality does not deteriorate.

Dyebath Decoloring

Dyebath decoloring by oxidation has been instituted full-scale at several mills. Chlorine is typically used as the oxidizing agent, but ozone can also be used. The technology is limited to dyestuffs that are amenable to decoloring. In general, acid, basic, direct, and disperse dyes are treatable, though not all dyestuffs in each class are treatable. More extensive use of this technology can be expected in the future, though the economics are not particularly promising.

The economics of activated carbon adsorption for dyebath decoloring are also not promising. Technically, most soluble dyestuffs can be adsorbed, and a colorless water produced for recycle. Operating costs, however, are usually close to, or greater than the cost savings realized through water, chemical, energy, and sewer use reduction. Thus, no incentive presently exists for more widespread use. Other adsorption technologies that would be less expensive to operate have been tested in the laboratory. These technologies use various exchange resins to adsorb the dyestuff molecules. Water recycle has not yet been demonstrated.

Membrane Separation Processes

Much laboratory and pilot-scale work has been done with membrane separation processes to recover and reuse dyestuffs from dye wastewater. Most notable are the use of hyperfiltration on continuous dye range wash water, and the use of ultrafiltration on wastewater from indigo dyeing. Hyperfiltration has been demonstrated as capable of producing a high quality water that can be recycled. For the process to be economical, however, the concentrated recovered dyestuff stream must be reused. Current full-scale testing at one finishing mill is presently attempting to resolve problems in this area and demonstrate complete reuse.

Ultrafiltration of indigo dye wastewater has been demonstrated and full-scale applications are now in place. The problem of dyestuff concentrate reuse is very much simplified in this application because only one dyestuff, rather than numerous mixtures, is used in dyeing. Limited future applications of membrane separation processes for dye wastewater recycle and reuse are seen at mills with large quantities of single dyestuff use, such as denim mills (indigo dye), and industrial fabric mills. More widespread use will depend on whether the problems with mixed dyestuff concentrate reuse can be resolved.

Coagulation

An alternate technology for dyestuff recovery has been investigated. Vat and sulfur dyes can be coagulated and removed from dye wastewater by the dissolved air flotation process. One full-scale application with indigo (vat) dye was built in the 1970's. While limited reuse was shown in the pilot-scale tests leading to full-scale design, dye recovery was never totally demonstrated before the mill closed, and treated water recycle proved too costly. Ultrafiltration appears to be a proven alternative to coagulation/flotation in this application and, therefore, no future applications of coagulation technology for dyestuff recovery are expected.

Other Technologies

Numerous examples of countercurrent use of wash water exist, and more widespread use can be expected due to the benefits of water and energy savings as well as the low capital cost involved.

Reuse of final rinse water for batch dyebath makeup has also been demonstrated at many textile mills. More widespread use of this technology is also expected since it involves only procedural changes to attain the cost benefits of water savings.

PRINTING

Printing wastes contain excess pigments, dyes, and solvents used in the printing process. Equipment cleaning water can be treated by coagulation/flotation and filtration, if needed, to produce a water that can be recycled for cleaning. Solvents, if used, can be extracted from the float and recovered for reuse. In some cases, cleaning water may require only filtration prior to direct reuse.

In mills where soaping or washing of the printed fabric is performed, countercurrent flow of washwater can be instituted. Cross-process use of soaper water in other processes, such as backgray washing, may be feasible.

Many finishing mills with printing operations are primarily involved in dyeing fabrics and perform only a limited amount of printing. Institution of coagulation/flotation facilities at these mills is not considered to be cost effective. A smaller number of finishing mills have extensive printing operations; many of these have coagulation/flotation facilities in place but only recover solvents or pretreat their printing wastewater prior to discharge. Expanded use of recycle of wastewater at these mills appears promising. But the further expansion of printwater recycle is not likely at printing mills that currently have no coagulation/flotation facilities, due to the high capital costs of the recycle technology and the long payback period involved. Further use of countercurrent flow on soapers can be expected due to the low capital cost and potential water and energy savings.

SECTION V

APPLICABILITY SURVEY

As noted in Section IV of this report, several technologies have been developed to allow recycle or reuse of textile finishing wastewaters. Many of these technologies hold promise for more widespread use within the textile industry in the future:

- Size recovery/reuse through ultrafiltration of desizing wastewater. Treated water from ultrafiltration is generally recycled to the desizing process.
- Caustic recovery/reuse through evaporation of mercerizing wastewater. Evaporator condensate is generally recycled to the mercerizing, scouring, or desizing process.
- Reconstitution/reuse of batch bleach and dyebaths.
- Dyestuff recovery/reuse through ultrafiltration or hyperfiltration of dyeing wastewater. Treated permeate is generally recycled to the dyeing process.
- Decoloring/recycle of dyeing wastewater by oxidation of dye molecules with chlorine (or ozone).
- Coagulation/flotation of printing wastewater to allow water recycle for equipment cleaning. Solvents may also be recovered from the float for reuse.
- Many forms of direct reuse including countercurrent washing, cross-process reuse, and reuse of dye rinse waters for dyebath makeup.

This section of the report presents the results of an applicability survey. The survey was conducted to identify how large a segment of the indirect discharge textile mill group has the potential for applying the above-mentioned recycle/reuse technologies.

SURVEY METHODOLOGY

Detailed manufacturing data from the BAT study industry survey in 1977 were available for 506 textile mills in the woven fabric, knit fabric, hosiery, carpet, and stock and yarn sectors. Candidate mills, or mills with a potential for adopting recycle, were identified from the data base of 506 mills by applying the following selection criteria:

1. Only indirect dischargers were selected for further consideration. Most direct dischargers have extensive end-of-pipe treatment systems for pollutant control, whereas indirect dischargers seldom employ more than screening or equalization for pretreatment. The greatest economic incentives and environmental benefits, therefore, would occur through the application of wastewater recycle/reuse by indirect dischargers.

2. Very small mills (generally, BAT economic model size 1 mills) were eliminated from further consideration on the grounds that these mills are more likely to be unable to realistically afford recycle/reuse technologies. Also, the economy of scale would favor medium and larger sized textile mills.

3. For the remaining textile mills, an evaluation of their manufacturing processes and the percentage of product through each process was conducted to determine if any of the available recycle/reuse technologies was potentially applicable. For example, a mill that mercerizes a substantial amount of its product, but does not currently employ caustic recovery, was considered to be a candidate.

4. Other factors, such as equipment age, sewer use charges, extent of pretreatment in place, and extent of recycle systems in place, were also considered in selecting candidate mills. In general, mills were considered as being more likely to install recycle/reuse systems if they possess newer processing equipment, have relatively high sewer use charges, have little pretreatment in place, or have not already evaluated or instituted recycle systems.

SURVEY RESULTS

Total Industry

As discussed in the methodology, the applicability survey focused on indirect dischargers in the major wet-processing sectors of the industry. Of the 506 mills in the initial data base, there were 367 indirect dischargers. These mills represent 43 percent of the 851 indirect dischargers identified in the BAT survey. Of these 367 mills, 151 mills, or about 40 percent, were selected as candidates for recycle/reuse technologies. A summary of these results is presented in

Table V-1. The data in the table are presented by industry sector (i.e., woven fabrics, knit fabrics, hosiery, carpet, and stock and yarn) and total industry to indicate the potential for application of recycle/reuse technologies in the industry. Table V-2 summarizes the technologies believed to be applicable to the candidate mills. Various mills are considered candidates for more than one technology, so the columns under the technologies shown on Table V-2 will not add up to the value of 151.

The selected mills represent over 40 percent of the indirect discharge flow and production from the sectors studied, and nearly 25 percent of the total industry flow and production.

It is likely that a substantial number of mills among those who did not provide detailed information are also candidates, thus further increasing the potential representation of the industry.

It should again be noted that a so-called candidate mill has been identified as having the potential for applying recycle/reuse successfully. A technical and economic feasibility study would be required to determine whether site specific factors, unit costs, and product quality requirements affect the potential for recycle/reuse technology applications at a given mill.

Woven Fabric Finishers

The 243 indirect dischargers in the woven fabric sector represent about 53 percent of the total (indirect plus direct) wastewater discharge and production in the sector. From the 88 indirect dischargers that provided detailed reports, 53 mills were selected as candidates for recycle/reuse technologies. These selected mills represent 55 percent of the indirect discharge flow and 54 percent of the production, indicating that a significant portion may benefit from the application of recycle/reuse technologies. As shown in Table V-2, the full range of technologies is applicable in this sector, most notably the hyperfiltration of dye wastewater (47 mills) and various other dyebath renovation technologies.

TABLE V-1
SUMMARY OF APPLICABILITY SURVEY RESULTS

Industry Sector	Number of Mills by Discharge Type		Percent Represented of Total BAT Survey Indirect Mills	
	Direct	Indirect	Flow	Production
Woven Fabric Finishing				
Total BAT Survey	85	243		
Detailed BAT Survey	63	88		
Recycle/Reuse Potential	--	53	55	54
Knit Fabric Finishing				
Total BAT Survey	39	232		
Detailed BAT Survey	31	110		
Recycle/Reuse Potential	--	24	17	22
Hosiery Finishing				
Total BAT Survey	7	153		
Detailed BAT Survey	3	55		
Recycle/Reuse Potential	--	18	32	32
Carpet Finishing				
Total BAT Survey	11	45		
Detailed BAT Survey	11	26		
Recycle/Reuse Potential	--	13	43	53
Stock and Yarn Finishing				
Total BAT Survey	36	178		
Detailed BAT Survey	31	88		
Recycle/Reuse Potential	--	43	62	43
Total Above Sectors				
Total BAT Survey	178	851		
Detailed BAT Survey	139	367		
Recycle/Reuse Potential	--	151	41	46

TABLE V-2

SUMMARY OF APPLICABILITY SURVEY OF RECYCLE TECHNOLOGIES

Industry Sector	Size Recovery	Caustic Recovery	Dyebath Renovation			Coagulation Print Waste	Direct Reuse
			Reconstitution	VF or HF	Oxidation		
Woven Fabric	15	7	17	47	26	15	53
Knit Fabric	--	--	16	--	8	4	24
Hosiery	--	--	18	--	10	--	18
Carpet	--	--	11	--	8	--	13
Stock/Yarn	--	1	36	4	12	--	43
Totals	15	8	98	51	64	19	151

Note: The values above represent the number of mills out of the survey base of 151 mills where recycle/reuse was judged to be applicable.

Knit Fabric and Hosiery Finishers

The 232 indirect dischargers in the knit fabric sector represent about 75 percent of the total wastewater discharge and 72 percent of the total production in the sector. Twenty-four (24) of the 110 mills providing detailed information were selected as candidates for recycle/reuse technologies. The selected mills represent 17 percent of the indirect discharge flow and 22 percent of the production, showing that a fairly small portion of the sector may benefit from the application of recycle/reuse technologies. The notable technologies are those applicable to renovation or recovery of dye wastewaters, such as reconstitution (16 mills), and decoloring by oxidation (8 mills).

The 153 indirect dischargers in the hosiery sector represent about 97 percent of the total wastewater discharge and 96 percent of the total production in the sector. Eighteen (18) of the 55 mills providing detailed information were selected as candidates for recycle/reuse technologies. The selected mills represent 32 percent of the indirect discharge flow and 32% of the production. The most promising technologies are reconstitution of dyebaths (18 mills) and dyebath oxidation/reuse (10 mills).

Carpet Finishers

The 45 indirect discharge carpet mills represent 81 percent of the total wastewater discharge and 78 percent of the total production in the sector. Of the 26 mills providing detailed information, 13 mills were selected as candidates for recycle/reuse technologies. The selected mills represent about 43 percent of the indirect discharge flow and 53 percent of the production, showing that a significant portion of the sector may benefit from application of recycle/reuse technologies. Technologies for renovation of dye wastewater are the most promising, particularly dyebath reconstitution (11 mills), and decoloring by oxidation (8 mills).

Stock and Yarn Finishers

The 178 indirect dischargers in the stock and yarn sector represent 67 percent of the total wastewater discharge and 53 percent of the total production in the sector. Forty-three (43) of the 88 indirect discharge mills providing detailed information were selected as candidates for recycle/reuse technologies. The selected mills represent 62 percent of the indirect discharge flow and 43 percent of the production, indicating that a significant portion of the sector may benefit from the application of recycle/reuse technology. The most notable technology is renovation of package dyeing wastewaters through reconstitution (36 mills). Other technologies include dye wastewater renovation by oxidation, and dyestuff recovery through ultrafiltration (indigo dyes).

CANDIDATE TECHNOLOGIES

As indicated previously, Table V-2 summarizes the extent of applicability of the various recycle/reuse technologies described earlier. The most potential exists for application of reconstitution of dyebaths from the various batch dyeing processes throughout the industry (98 mills). Many other dyebath renovation technologies, including oxidation and hyperfiltration, also appear to have widespread potential.

Membrane Separation Processes

The potential for application of ultrafiltration is focused in the woven fabric sector (15 mills) for recovery of size, and the yarn sector for recovery of indigo dye (4 mills). Hyperfiltration for dye recovery can potentially be applied in the woven fabric (47 mills) sector, assuming that concentrate reuse problems can be resolved.

Dyebath reconstitution generally appears more appropriate than membrane processes in the knit fabric, hosiery, carpet, and stock and yarn sectors due to their extensive use of batch dyeing.

Evaporation

The potential applications of evaporation for caustic recovery occur in the woven fabric (7 mills) and stock and yarn (1 mill) sectors where mercerizing is practiced and recovery has not yet been instituted.

Reconstitution

Dyebath reconstitution technology shows promising applications in all the industry sectors studied. Ninety-eight (98) mills possess a potential for applying reconstitution. It is especially noteworthy for the knit fabric, hosiery, carpet, and yarn sectors because of their extensive use of batch dyeing.

Oxidation

Dyebath oxidation potentially may be applied in the woven fabric (26 mills), knit fabric (8 mills), hosiery (10 mills), carpet (8 mills), and stock and yarn (12 mills) sectors for decolorizing dye wastewaters from water-soluble dyes. In many cases, this technology is in direct competition with reconstitution for dyebath renovation. Oxidation may be particularly useful in cases where reconstitution proves unfeasible.

Coagulation

Coagulation may be applied in the woven fabric (15 mills) and knit fabric (4 mills) sectors for coagulation of print wastewater for water recycle. Solvent recovery should also be investigated at mills using solvents in their printing operations.

Direct Recycle/Reuse of Water, Cross-Process Water Reuse, Water Reduction, and In-Plant Housekeeping Measures

Direct reuse technologies and water reduction techniques are applicable throughout the industry, and most mills are considered as candidates for developing programs such as those detailed in the literature. In most cases, water reduction techniques should be instituted prior to wastewater recycle technologies so as to minimize the amount of water needing treatment prior to recycle.

SECTION VI

SIZE RECOVERY BY ULTRAFILTRATION

INTRODUCTION

A variety of sizing chemicals is used in the woven fabric finishing sector of the textile industry to strengthen and smoothen warp yarns prior to weaving. The primary consideration in selecting a size is to provide a warp that weaves at high efficiency. Easy removal and recovery of the size before dyeing and finishing have not always been given careful consideration.

Historically, starch has been the primary size compound used in weaving due to high volume of cotton fabrics, but the recent, more widespread use of man-made fibers brought about the development of chemically modified starches and man-made polymers. Polyvinyl alcohol (PVA) and carboxymethyl cellulose (CMC) are used widely with cotton/synthetic blends, and acrylic and polyester sizes are used with filament yarns. Starch/PVA mixtures find common application on cotton-polyester blends, and starch is still widely used on cotton fabrics.

All of these sizes must be removed in the desizing process prior to dyeing and finishing. The desizing procedure varies with the size, yarn, and fabric. Generally, starch removal consists of degradation to a water-soluble form (hydrolysis) followed by washing. PVA and CMC removal require only hot water and mechanical action. Acrylic and polyester sizes require hot alkaline scours.

The resulting desizing wastewater is high in BOD in the case of starch desizing, and high in COD for the cases of desizing the synthetic sizes; the synthetic sizes generally exhibit a low BOD. The resulting pollution problem and the loss of valuable size prompted investigations of methods for size recovery.

The most promising technology for size recovery is ultrafiltration, a low pressure (60 to 150 psig) membrane separation process that can be used to concentrate the size compounds from desizing wastewater. Figure VI-1 provides a process schematic for this recycle

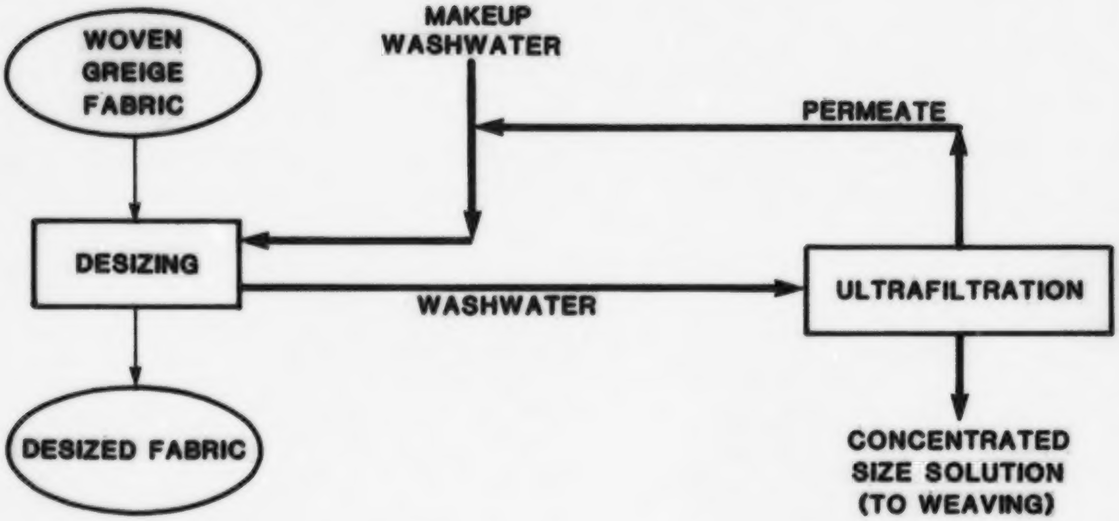

WOVEN GREIGE FABRIC
MAKEUP WASHWATER
PERMEATE
DESIZING
WASHWATER
ULTRAFILTRATION
DESIZED FABRIC
CONCENTRATED SIZE SOLUTION (TO WEAVING)

FIGURE VI-1
PROCESS SCHEMATIC
SIZE RECOVERY BY ULTRAFILTRATION

technology. Ultrafiltration has been successful for recovery of PVA, modified PAA (acrylic) and CMC. The recovered size is reused for slashing (sizing), while the treated wastewater is reused in the desizing process.

Several other recycle technologies have been investigated for size recovery, including coagulation, evaporation, and precipitation techniques. These technologies have not been demonstrated commercially, and some technical problems remain. They are discussed further in Section XIV of this report.

A critical factor in the success of size recovery technology is the type of sizing compound present on the greige fabric. Phase II investigations at Mill W-8 (see Appendices) revealed that starch is degraded to an extent such that it is difficult to recover through either ultrafiltration or hyperfiltration (a higher pressure membrane separation process), and the recovered concentrate is not reusable for sizing or even as a fabric handbuilding agent.

At Mill W-4, it was found that acrylic sizes are degraded in the alkaline desize bath to the extent that they also are difficult to recover and reuse. Mill W-3 demonstrated the difficulties involved with commission finishing of fabrics received from various greige mills that use starch, PVA, or mixtures thereof. Problems were encountered in identifying the amount and type of size on the incoming fabrics so that the mill employed desizing procedures that would be sure to remove both types of size. Many commission finishers fall into this category, and the uncertainty of the success of recovery and the marketability of the recovered size prevents them from investigating size recovery in detail. Another deterrent is that even if PVA can be recovered from PVA-starch mixtures in desizing wastewater, the treated water still contains the starch impurities, likely rendering it non-recyclable. This further impairs the cost effectiveness of instituting size recovery technology.

The only successful full-scale applications of ultrafiltration are for PVA recovery. These applications have resulted in water, chemical, energy, and pollutant surcharge savings, with typical payback periods from nine months to two years. The remainder of this section thus focuses on PVA recovery by ultrafiltration.

ENVIRONMENTAL BENEFITS

Desize wastewater generally contains substantial concentrations of BOD, COD, and TSS, depending on the size and fabric being processed. Most of these pollutants are a direct result of the size itself, so that size recovery will effect a reduction of BOD, COD, and TSS proportional to the load contributed by the desizing process. The ultimate effect on a mill's final discharge depends on the amount of desizing conducted at a mill in relation to other processes.

Three of the six mills investigated during Phase II of this project have large desizing operations. The data presented below indicate the large amount of the total waste load attributable to the removed sizing compounds:

	Product	% Waste Load from Desizing/Scouring			
Mill	Desized	Flow	BOD	COD	TSS
W-4	30%	4	12	9	20
W-8	95%	29	26	61	48
W-3	100%	29	81	73	38

Size recovery at these mills, if practical, would therefore result in significant environmental benefits.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description

The heart of the ultrafiltration process is the semi-permeable membrane. The membrane allows water to pass, while the high molecular weight size compound is retained on the feed side of the membrane. Water flux through the membrane (F) is generally defined as

$$F = \frac{K \Delta P}{V}$$

where V is the water viscosity, ΔP is the pressure difference across the membrane, and K is a membrane resistance coefficient. This coefficient is temperature-dependent, increasing with higher temperatures. Thus, higher temperature operation generally results in higher flux rates. Other factors, such as flow turbulence, and the buildup of a size layer on the membrane, can affect the flux rate.

Membrane technology has developed significantly in recent years, and membranes applicable in a wide range of conditions are now available. The membranes are marketed in four basic configurations:

- Tubular
- Spiral-wound
- Hollow fiber
- Plate and frame

To date, the tubular and spiral-wound configurations have been applied for size recovery, so only these will be discussed in more detail.

Tubular Configuration. The tubular configuration for size recovery has been primarily marketed by Gaston County Filtration Systems of Stanley, North Carolina (GCFS). The GCFS unit employs a 6 mm I.D. porous carbon support tube that supports an inert zirconium oxide membrane. Figure VI-2 shows a typical tubular ultrafiltration assembly.

Approximately 1000 tubes are assembled in a shell and tube configuration known as a module, and two modules combine with a recirculation pump to form a loop.

The desizing wastewater circulates through the inside of the tube. Water and desize bath chemicals, such as soda ash or detergent, generally permeate the membrane to the shell side of the module, while the concentrated size solution remains in the loop.

The rate of the permeate discharge (flux rate) is usually expressed in gallons per square foot of membrane area per day (GFD). Resistance to flux is caused by the carbon tube, membrane, fouling, and boundary layer filter cake or gel formation. Although the cross-flow mode of filtration tends to be self-cleaning as the cross flow reduces the accumulation of filtered material, there will be a buildup of size, wax, and oils on the membrane. Therefore, periodic cleaning with caustic, peroxide, or mild acid is recommended to reduce fouling and maintain a high flux rate. The filter cake or gel layer is affected by the nature and concentration of the recovered materials and the circulation rate through the tubes.

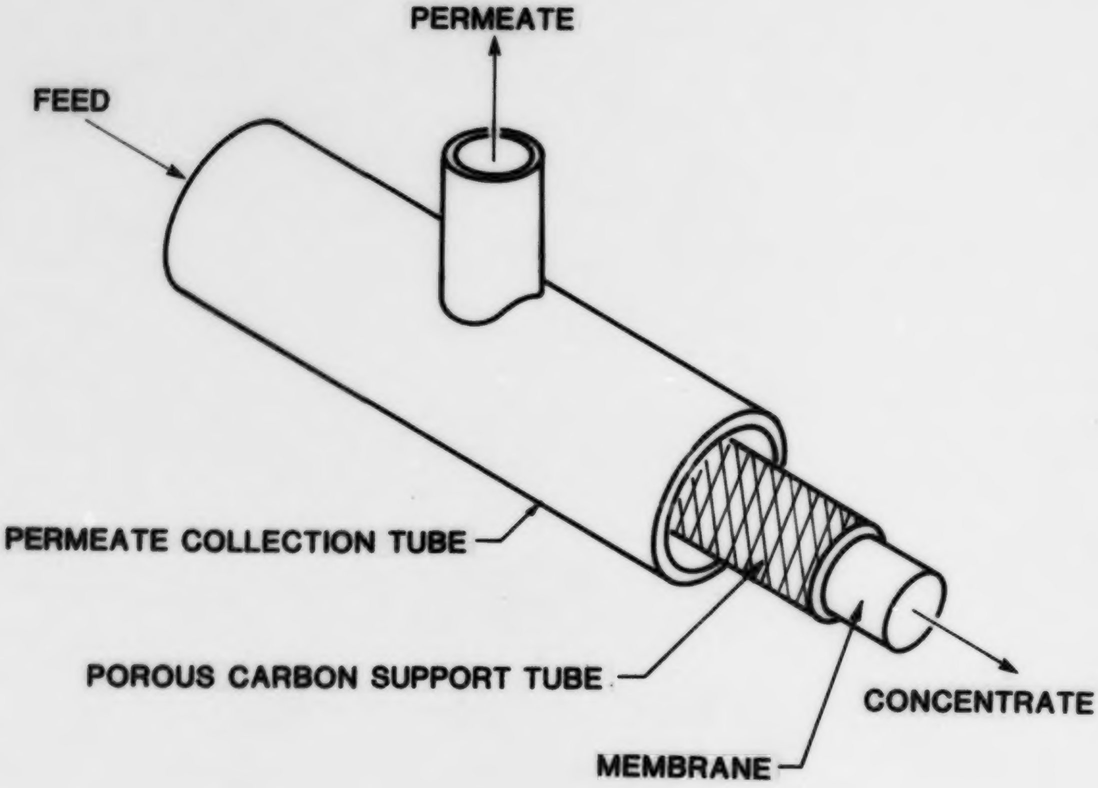

PERMEATE
FEED
PERMEATE COLLECTION TUBE
POROUS CARBON SUPPORT TUBE
CONCENTRATE
MEMBRANE

FIGURE VI-2 TUBULAR ULTRAFILTRATION MODULE

In general, flux rate is maintained or enhanced by low viscosity/high temperature conditions, and low concentration/high circulation rates. Temperatures near 100°C and circulation rates near 1400 gpm (10 fps velocity) minimize filter cake resistance.

Spiral Wound Configuration. The spiral wound configuration for size recovery has been marketed primarily by Abcor, Inc., Wilmington, Massachusetts. The structure of a typical spiral wound module is illustrated in Figure VI-3. It is essentially a sandwich of two membrane sheets with a permeate conducting layer between them. The membranes most applicable in the textile industry are manufactured from proprietary non-cellulosic polymers with the ability to operate under a wide range of pH (2 to 9) and temperatures (25 to 90°C). A turbulence-promoting spacer sheet is placed between membrane sandwiches, and the entire array is rolled around a perforated permeate collection pipe. This cylindrical module fits into a shell.

The turbulence-promoting spacer lends rigidity between membrane and forms a flow passage for the feed stream. The passage contains numerous disturbances that promote a higher mass transfer rate.

Comparison of Tubular and Spiral-Wound Configurations. Table VI-1 presents a comparison of the tubular and spiral-wound configurations. The implications for a size recovery system are that the tubular configuration should be less likely to foul because of the greater turbulence, and the membranes are simpler to clean. Higher flux rates are achievable as long as the feed temperature is kept very high (above 85°C) to maintain low viscosity. At the higher viscosities associated with lower temperatures, the flux increases only slightly as flow rate increases, thereby eliminating the advantage of the tubular configuration and emphasizing the advantage of the spiral wound configuration. The advantages particularly emphasized at lower temperatures/higher viscosities are the low flow velocity requirement, low pumping requirement, and high membrane area/volume ratio.

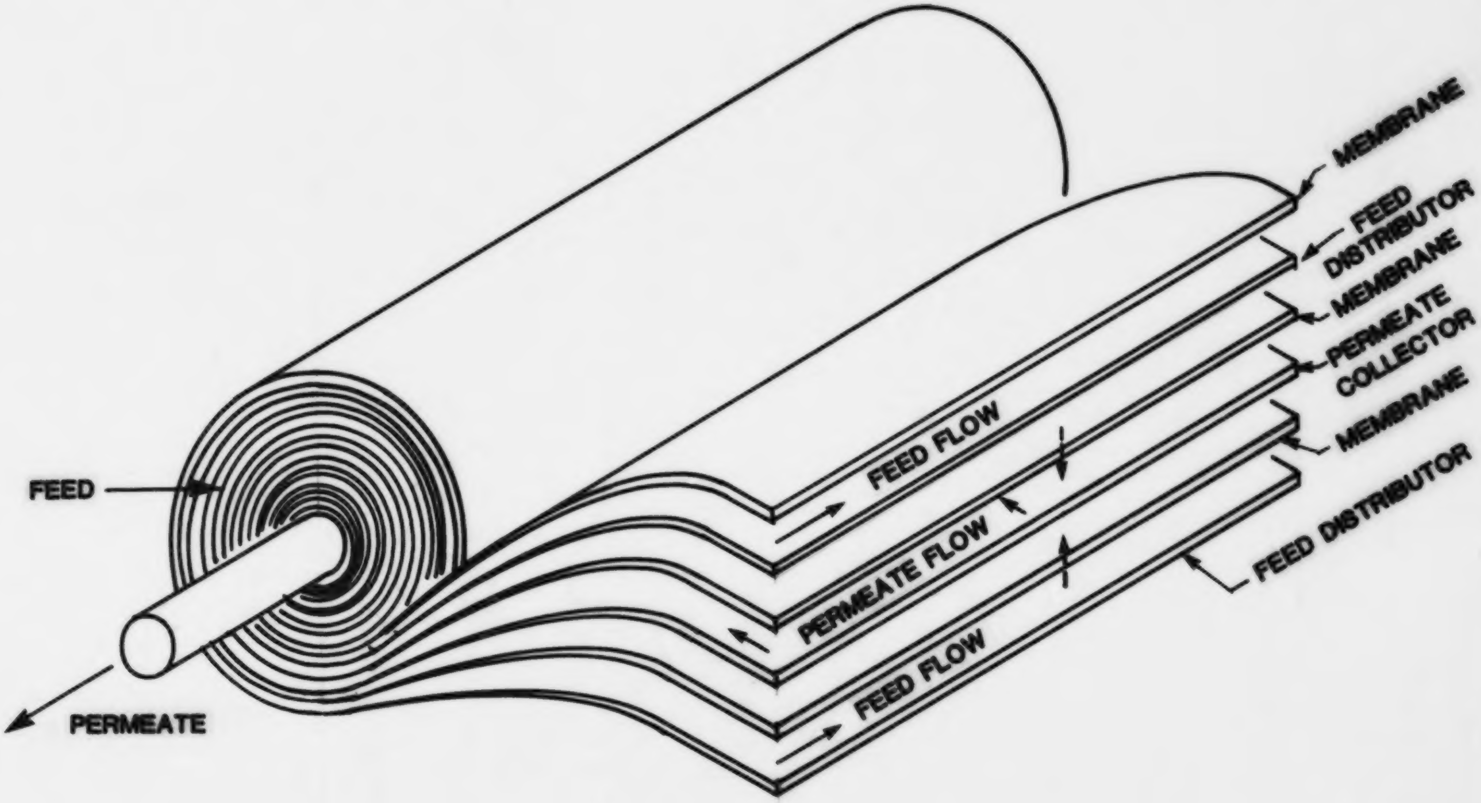

MEMBRANE
FEED DISTRIBUTOR
MEMBRANE
PERMEATE COLLECTOR
MEMBRANE
FEED DISTRIBUTOR
FEED FLOW
PERMEATE FLOW
FEED FLOW
FEED
PERMEATE

FIGURE VI-3
SPIRAL WOUND MEMBRANE

TABLE IV-1
COMPARISON OF TUBULAR AND SPIRAL-WOUND CONFIGURATIONS

	Tubular	Spiral-Wound
Flow passage	Open	Tortuous flow
Velocity	High	Low
Flow regime	Turbulent	Laminar with eddy promotion
Pumping requirements	High	Low
Fluid Viscosity	Low, < 30 cp	High, > 30 cp
Prefiltration	No	Yes
Membrane area/volume	Low	High
Chemical cleaning	Yes	Yes
Mechanical cleaning	Yes	No
Flux level	High	Low
Flux-flow dependency	Sensitive	Not important
Cost/permeate volume	Low	Low

Source: Reference 8

In applications to date, the tubular configuration has demonstrated much longer membrane life (7 years) than the spiral-wound (2 years), mostly due to greater ease of maintenance. It appears that the mills maintain high temperatures/low viscosities in the desize wastewater, thus enabling the success of the tubular configuration.

Although the spiral wound configuration exhibits the traits of greater membrane area per volume and lower pumping requirements, the requirements for prefiltration are strict, and fouling has led to shorter membrane life.

Design Criteria

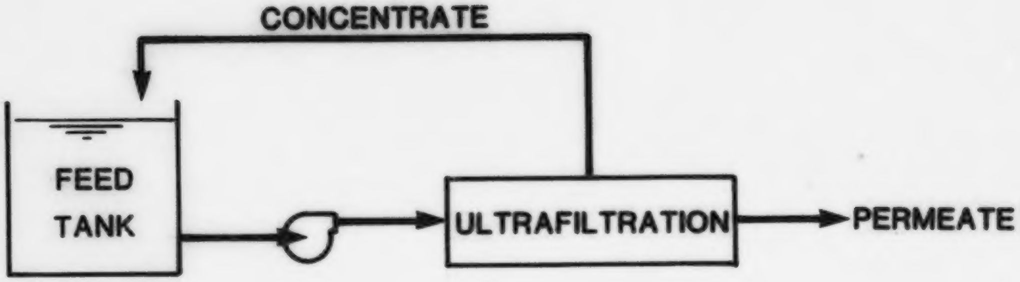
Control Modes. Several control modes need to be considered for design and operation of an ultrafiltration system. These are simple batch, semi-continuous batch, feed and bleed batch, and multi-stage continuous. These are described below and illustrated in Figures VI-4 and VI-5.

The simple batch mode requires the least membrane area and largest amount of feed tank volume. Permeate is removed continuously, while the loop concentrate is returned to the feed tank. Thus, the feed tank contents are gradually concentrated. This mode yields the highest average flux and is suited for small systems with a sharply declining flux curve.

The semi-continuous batch mode reduces the required tank volume by allowing fresh feed to enter the feed tank up to a certain time, after which the fresh feed is stopped and the system continues to operate in the batch mode. This mode may be considered for moderate flows of dilute concentrations.

The feed and bleed batch mode allows for the recirculation of most of the feed in a loop through the membrane, rather than through the feed tank. A small percentage (5 to 20 percent) is bled back to the feed tanks. This mode is advantageous for systems in which the feed tank must be located far from the ultrafiltration system, and it is more energy efficient because the feed in the recirculation loop remains at about 20 psig at the suction of the circulation pump, as opposed to 0 psig at the feed tank.

SIMPLE BATCH


CONCENTRATE
FEED
TANK
ULTRAFILTRATION
PERMEATE

SEMI-CONTINUOUS BATCH

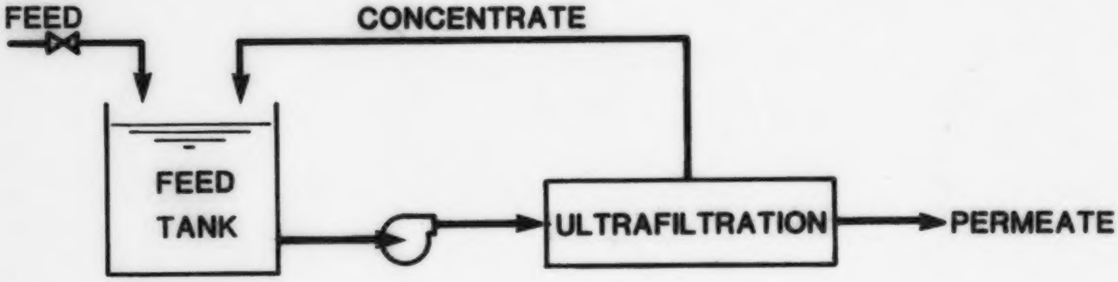
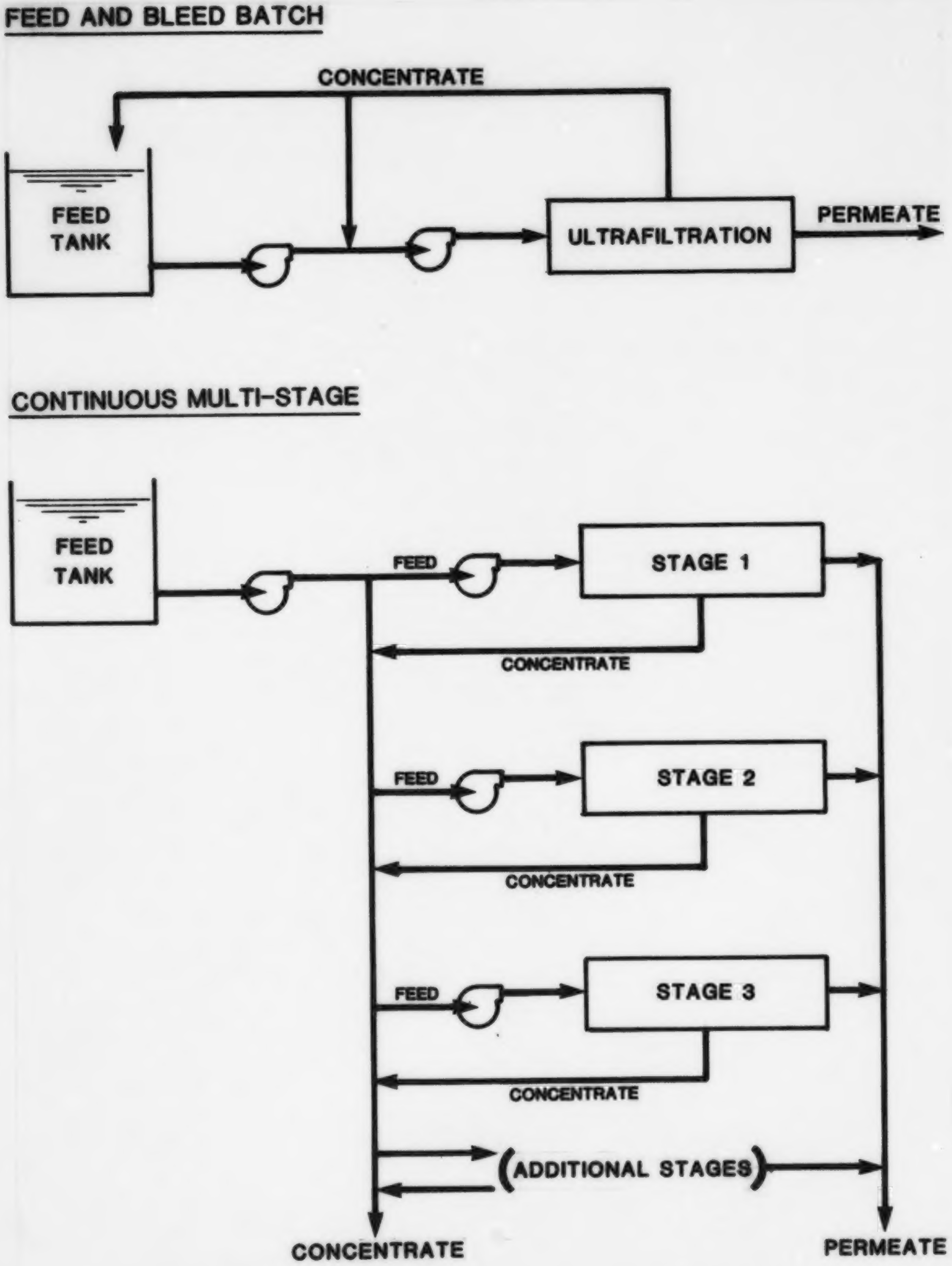

FEED
CONCENTRATE
FEED
TANK
ULTRAFILTRATION
PERMEATE

FIGURE VI-4 SIZE RECOVERY CONTROL MODES



FEED AND BLEED BATCH

CONTINUOUS MULTI-STAGE

CONCENTRATE
FEED TANK
ULTRAFILTRATION
PERMEATE
FEED TANK
FEED
STAGE 1
CONCENTRATE
FEED
STAGE 2
CONCENTRATE
FEED
STAGE 3
CONCENTRATE
(ADDITIONAL STAGES)
CONCENTRATE
PERMEATE

FIGURE VI-5 SIZE RECOVERY CONTROL MODES

The multi-stage continuous mode allows the concentrate to discharge only at the desired final concentration. Permeate is continuously withdrawn as in the batch modes. The average permeate flux is below that of the batch modes, but approaches that of the batch modes as the number of stages increases. This mode also minimizes feed tank volume requirements. The residence time of the fluid being concentrated is mimimized, which is important to materials that may degrade biologically. This mode is most economical for very large systems.

System Design

Consideration must be given to the relationships between process variables such as inlet pressure, feed velocity, temperature, and flow channel dimensions, and the parameters of concentration, viscosity, pressure drop, osmotic pressure, and flux. The optimum design balances the membrane area and pumping power costs. As stated earlier, the higher the temperature, the lower the apparent viscosity and module pressure drop. Important relationships are listed briefly below:

- Osmotic pressure is a function of concentration.
- Apparent viscosity is a function of concentration, temperature, and feed velocity.
- Pressure drop is a function of viscosity and flow channel dimensions (Reynolds Number)
- Pressure driving force depends on inlet pressure, module pressure drop, and osmotic pressure
- Permeate flux depends on the membrane, temperature, pressure driving force, and feed velocity and concentration.

The recycle volume and module pressure drop determine the running costs. Inlet pressures range from 60 to 150 psig.

Flux rates established in full scale and pilot scale applications have ranged from 30 GFD to 100 GFD; it is strongly recommended that flux data be developed on a pilot scale for a particular waste stream to optimize the design.

A flow diagram of a typical PVA recovery system is shown in Figure VI-6. It illustrates that filtration and flow balancing are required prior to the ultrafiltration system. The permeate returns to the desize bath, except for a small blowdown, and the concentrate remains in the loop until the desired concentration is reached. A ten percent concentration level is typically desired. This concentrate is transported to the PVA mixing tank for reuse at the slasher. In some applications, the concentrate may need additional treatment such as centrifuging to remove excess wax and oils. The degree and type of prefiltration vary depending on the membrane type and configuration, as discussed in the comparison of tubular and spiral-wound configurations.

Performance and Operating Characteristics

The parameters used to characterize system performance are rejection and yield. The rejection (R) is the percentage of size that does not pass through the membrane.

$$R = \frac{\text{feed size concentration - permeate size concentration}}{\text{feed size concentration}} \times 100\%$$

Yield (Y) is the percent of size originally in the desize wastewater that is recovered in the ultrafiltration concentrate.

$$Y = \frac{\text{amount of size in concentrate}}{\text{amount of size in feed}} \times 100\%$$

Values for rejection generally exceed 98% in successful applications, and yield values generally exceed 96%.

FACTORS LIMITING TECHNICAL FEASIBILITY

In order to realize adequate economic benefits through size recovery, the following conditions must generally be met:

1) Desizing wastewater must be segregated from other plant wastewater.

2) A single type of size compound (or a mixture compatible for reuse) must be used.

3) Desize wastewater should contain about 1 to 1.5% size compound, which may require desizing process water use reduction.

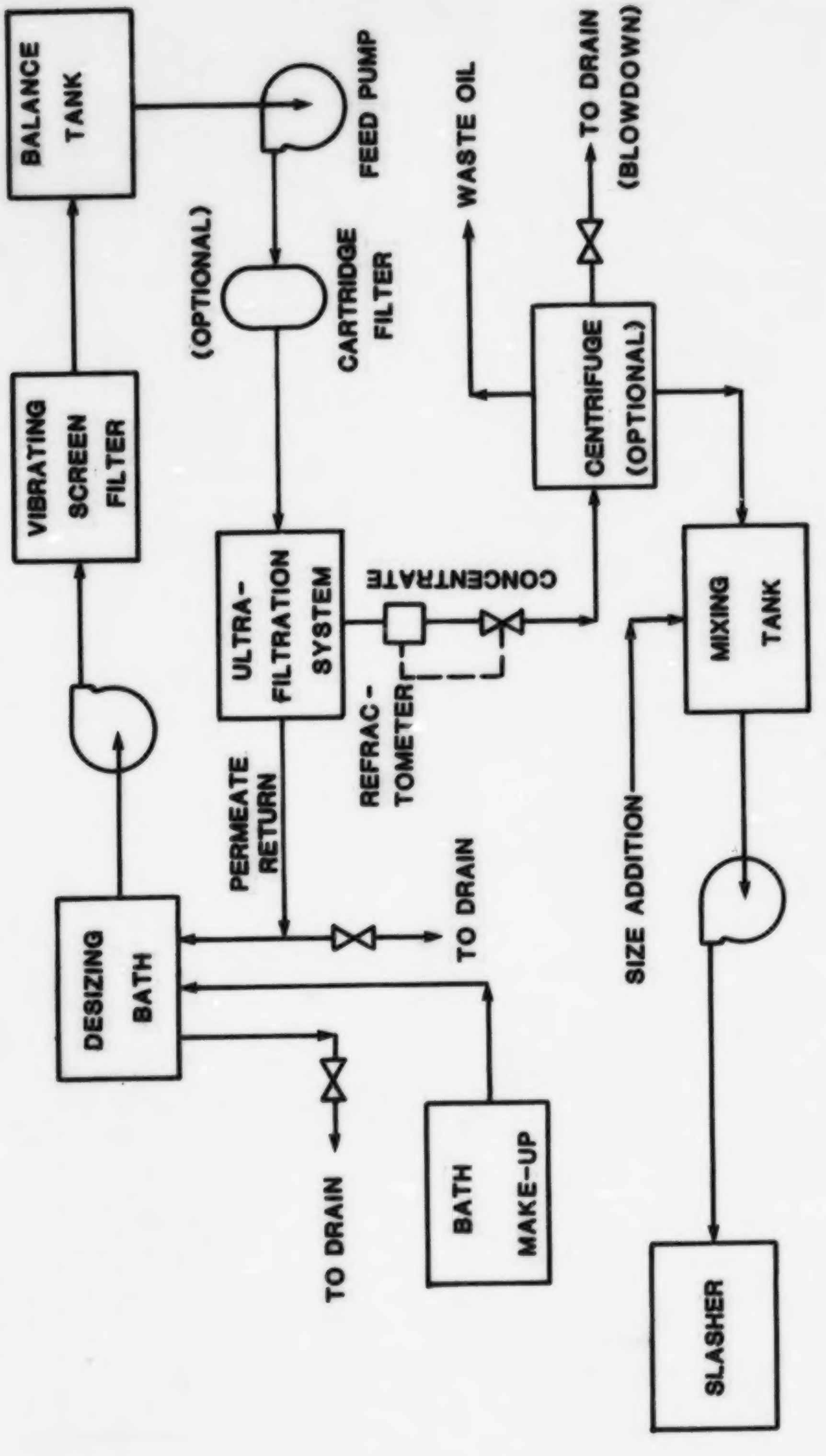

DESIZING BATH
VIBRATING SCREEN FILTER
BALANCE TANK
FEED PUMP
(OPTIONAL)
CARTRIDGE FILTER
ULTRA-FILTRATION SYSTEM
PERMEATE RETURN
TO DRAIN
TO DRAIN
BATH MAKE-UP
REFRAC-TOMETER
CONCENTRATE
CENTRIFUGE (OPTIONAL)
WASTE OIL
TO DRAIN (BLOWDOWN)
SIZE ADDITION
MIXING TANK
SLASHER

FIGURE VI-6 SIZE RECOVERY SYSTEM SCHEMATIC

4) An outlet for recovered size must be conveniently available.

5) Steps must be taken to prevent size degradation in the bath or subsequent storage.

6) Some sizes may be destroyed by excessive agitation during processing or recovery. Care must be taken to prevent high degrees of agitation.

7) Some fabrics may be treated with oils that will tend to gum up sizes during recovery. Centrifuging may be necessary to separate the oils from the recovered size.

8) Permeate reuse may not be feasible with certain fabrics due to the occasional buildup of waxes and degraded size in the permeate.

ECONOMIC ANALYSIS

Capital Cost

Capital cost data for ultrafiltration systems are rather limited. Vendors of ultrafiltration equipment have provided quotations and estimated costs curves for their equipment based on a limited number of full-scale size recovery systems. Allowances for installation, tankage, piping, filters, electrical work, engineering, and contingencies were added to the quoted vendor equipment costs as indicated below to obtain total capital costs:

Ultrafiltration equipment	Base
Equipment installation	7%
Tankage, piping, filters	20%
Electrical	5%
Engineering	8%
Contingency	10%
Total	150% of base cost

Figure VI-7 shows the resulting capital cost of the size recovery system versus treated desize wastewater flow. Costs are adjusted to June 1983 dollars.

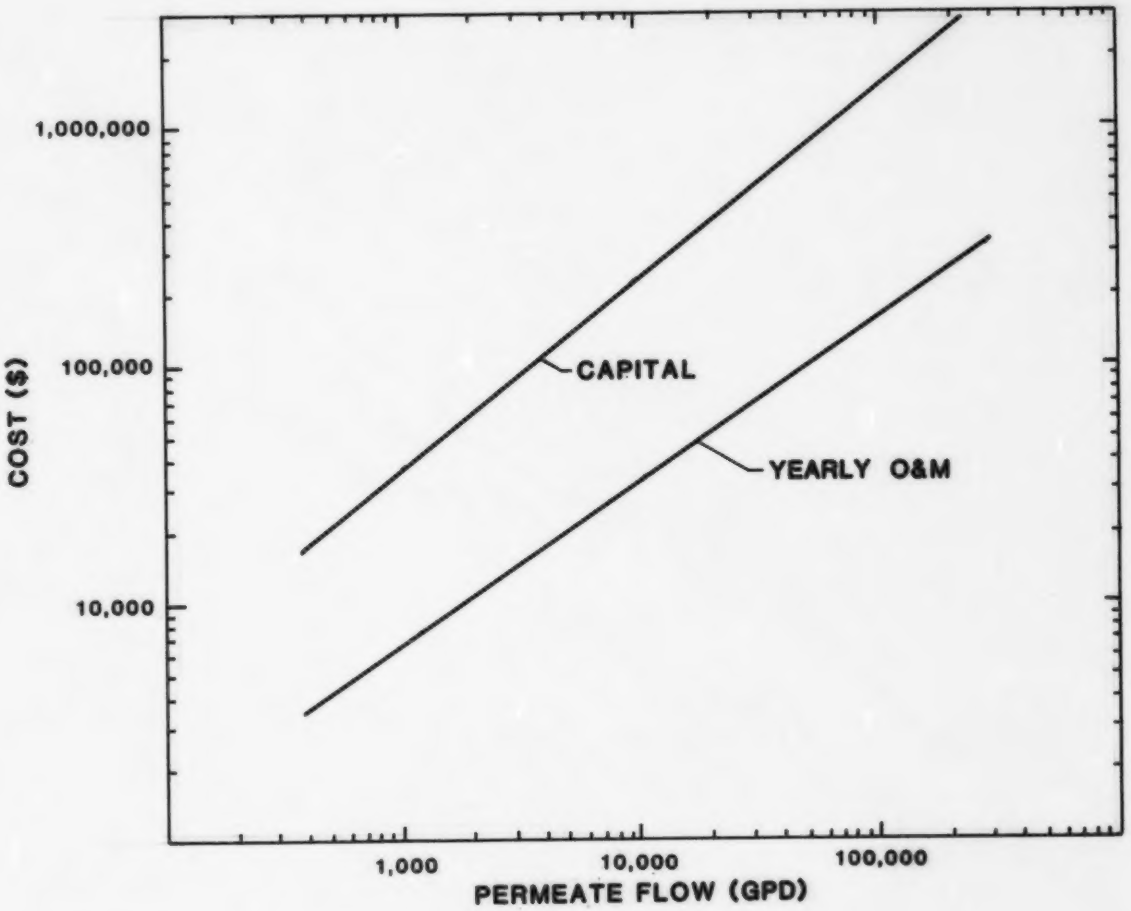


FIGURE VI-7 SIZE RECOVERY SYSTEM COSTS (JUNE 1983)

Operating Cost

Estimated yearly operating and maintenance costs are also shown on Figure VI-7. These costs are based on vendor estimates and include operating labor, maintenance labor, maintenance parts, replacement membranes, and pumping costs. Labor and membrane replacement costs make up the bulk of the annual operating and maintenance costs.

Baseline Economics

To provide a starting point for determining the economics of this technology, a baseline or model case was examined. The results are presented in Table VI-2. The assumptions used in developing the baseline analysis are presented in Table VI-3.

Factors Affecting Economics

The primary factor influencing the economics of size recovery is the concentration of size in the desizing wastewater. A secondary factor is the value/marketability of the recovered size. These are examined in more detail below.

Concentration of Size in Desize Wastewater.

The cost effectiveness of a size recovery system is dependent on the original size concentration in the desize wastewater. Lower size concentrations require a larger volume of water to be treated by ultrafiltration to recover a given amount of size. This increases the capital cost of the treatment system. Figure VI-8 shows the effect of varying size concentrations on the payback period. The assumed concentration for reuse is 10 to 12 percent at the slasher. Figure VI-8 shows that the size concentration in the wastewater must be greater than 0.5 percent to operate economically at the current costs of operation and values of chemical recovery.

TABLE VI-2

BASELINE ECONOMICS
SIZE RECOVERY BY ULTRAFILTRATION

Capital Cost	100,000 gpd	$1,300,000
Yearly O&M Cost	100,000 gpd	$ 150,000
Yearly Savings		
Size Recovery	6,670 lb/day	$2,000,000
Water & Sewer	80,000 gpd	24,000
Energy	67×10^6 BTU/day	80,000
COD (Surcharge Sewer Use)	6,250 lb/day	280,000
	Subtotal	$2,384,000
Net Annual Savings		$2,234,000
Payback Period	$1,300,000/2,234,000/yr. =	7 months

TABLE VI-3
BASIS FOR ECONOMIC ANALYSIS
SIZE RECOVERY BY ULTRAFILTRATION

Desize Production: 100,000 lb fabric/day
300 days per year

Water Use: 1 gal/lb fabric

Wastewater: 100,000 gpd

Size Concentration in Desize Wastewater: 1%

Size Concentration for Reuse: 10%

Recovery Efficiency: 80%

Cost of Size (PVA): $1/lb

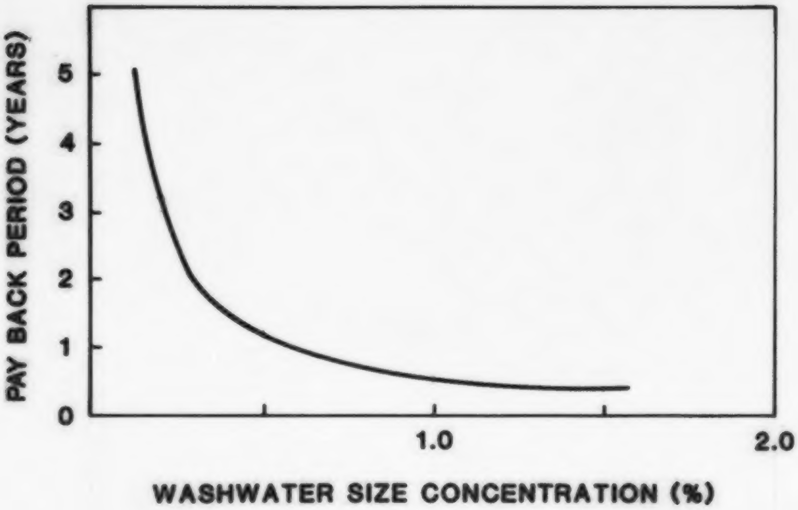
Water Savings: $0.50/1,000 gallons

Sewer Use Savings: $0.50/1,000 gallons

Energy Savings: $4/million BTU
Permeate is 100°F hotter than plant water

Power Cost: $0.05/kwhr

Desize Wastewater COD Concentration: 10,000 mg/l
Desize Wastewater COD load: 8,340 lb/day
COD Removal by UF: 75%
COD Savings: $0.15/lb (Sewer Use Surcharge)



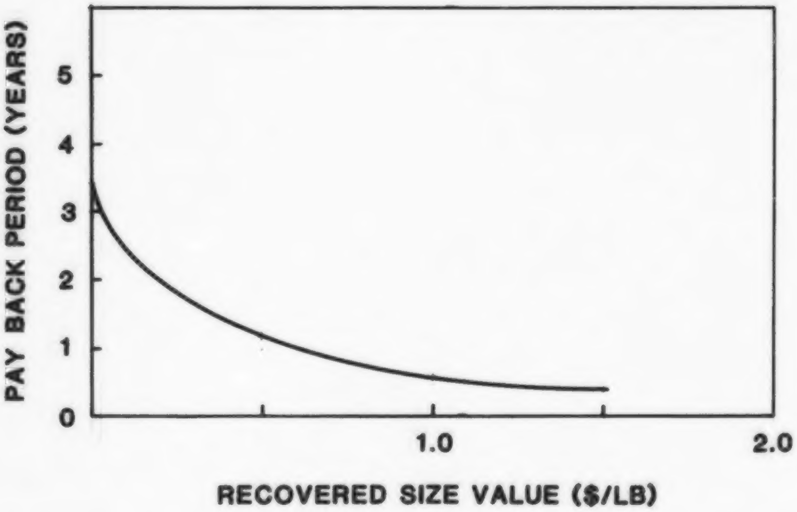


FIGURE VI-8 EFFECT OF VARIABLES ON SIZE RECOVERY ECONOMICS

Value/Marketability of the Recovered Size. It is apparent that the recovered size must have a convenient outlet for its reuse in order to provide the maximum savings. The value will decrease if the size must be hauled or chemically modified, thus decreasing chances for an acceptable payback period. For example, if the value of the recovered size in the model case were only $0.50/lb, the net annual savings would decrease by $1 million, thereby increasing the payback period to approximately one year. Figure VI-8 shows the effect of varying the value of recovered size on the payback period.

CURRENT APPLICATIONS

Several full scale applications for size recovery are known at the present time. These include Gaston County units at J. P. Stevens Delta 1 in Clemson, S.C., Milliken Magnolia in Blacksburg, S.C., Milliken Excelsior in Pendleton, S.C., and Spring Mills in Lancaster, S.C. Spring Mills also has applied an Abcor unit successfully over several years.

Gaston County states they have eight full scale installations in place now, including the locations identified above.

Other research at a pilot scale has been conducted by Groves et al. in South Africa and CARRE, Inc., in South Carolina.

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SECTION VII

CAUSTIC RECOVERY BY EVAPORATION

INTRODUCTION

Evaporation, a process in which a non-volatile solute is concentrated through heat-induced vaporization of the solvent, is used in the textile industry to concentrate caustic (NaOH) from mercerizing rinse water. A concentrated (25 to 35 percent) caustic solution is produced for reuse, enabling the recovery and reuse of caustic, versus purchase of virgin caustic at a current price of $250 to $300 per ton. Reuse of hot evaporator condensate enables energy recovery and results in water savings. Caustic recovery can also result in savings in wastewater neutralization costs. Typical payback periods for caustic recovery systems are less than one year, but vary with site-specific conditions. A successful but small installation at Mill W-3 was examined under Phase II of this project and shown to have a payback period of about two years.

ENVIRONMENTAL BENEFITS

Data from Mill W-3 indicate that mercerizer wastewater is relatively clean with respect to pollutant parameters such as BOD, COD, TSS, phenolics, and metals. The primary environmental benefit of recycle/reuse of the wastewater is to decrease the alkalinity and pH of the final effluent. Total alkalinity from the Mill W-3 bleach house is decreased by about 80 percent by the caustic recovery system. Water use in the bleach house is reduced about 10 percent by the reuse of hot evaporator condensate.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description

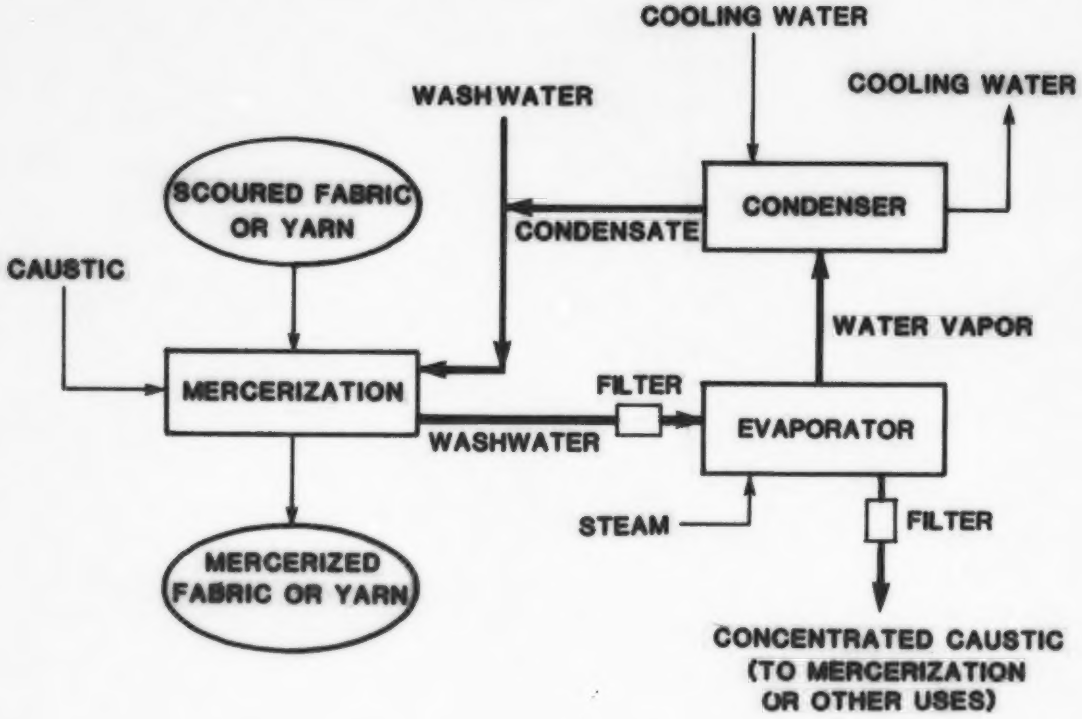
The three principal elements of evaporation technology are heat transfer, vapor-liquid separation, and energy utilization.

Typically, heat transfer is achieved by means of shell and tube heat exchangers, though certain applications employ flat plates, coils, jackets, double walls, direct contact, or solar radiation. The shell and tube design has been used more extensively than the others. A complete discussion of heat exchangers is beyond the scope of this report, and the references provide further information.

The heat exchanger is used in conjunction with a chamber for vapor-liquid separation, known as a body, vapor head, or flash chamber. The term "body" also refers to the combination of heat exchanger and chamber, and the term "effect" refers to one or more bodies boiling at the same pressure.

Figure VII-1 is a process schematic for caustic recovery technology. As shown, wastewater from the mercerizing process is filtered to remove gross solids and lint before entering the evaporator. Most of the water is evaporated, leaving a concentrated caustic solution. The water vapor is condensed and reused at the mercerizing process or other processes requiring hot water. Concentrated caustic is filtered and returned to the mercerizing process or other processes requiring the use of caustic. Known installations for caustic recovery employ multiple-effect evaporators in which the vapor from one effect is used to heat the following effect, boiling at a lower pressure. This maximizes the energy efficiency of the process. A schematic diagram of a double-effect evaporator is provided in Figure VII-2. Typically, a partial vacuum is created in the second effect to allow boiling at a lower pressure and to efficiently use the energy (heat) in the vapor produced in the first effect.

The efficiency of energy utilization is evaluated on the basis of steam economy--the amount of solvent evaporated per pound of steam used. Theoretically, a single-effect evaporator requires one pound of steam to evaporate one pound of water. In a multiple-effect evaporator, if the feed to each effect is near the boiling point, then one pound of steam will evaporate one pound of water in each effect. Thus, an increase in the number of effects improves the steam economy. In actual practice, however, the steam economy is less than theoretical. A


COOLING WATER
COOLING WATER
WASHWATER
SCOURED FABRIC OR YARN
CONDENSER
CONDENSATE
CAUSTIC
WATER VAPOR
MERCERIZATION
FILTER
EVAPORATOR
WASHWATER
STEAM
FILTER
MERCERIZED FABRIC OR YARN
CONCENTRATED CAUSTIC (TO MERCERIZATION OR OTHER USES)

NOTE: SINGLE EFFECT EVAPORATOR SHOWN FOR SIMPLICITY.

FIGURE VII-1
EVAPORATION PROCESS SCHEMATIC

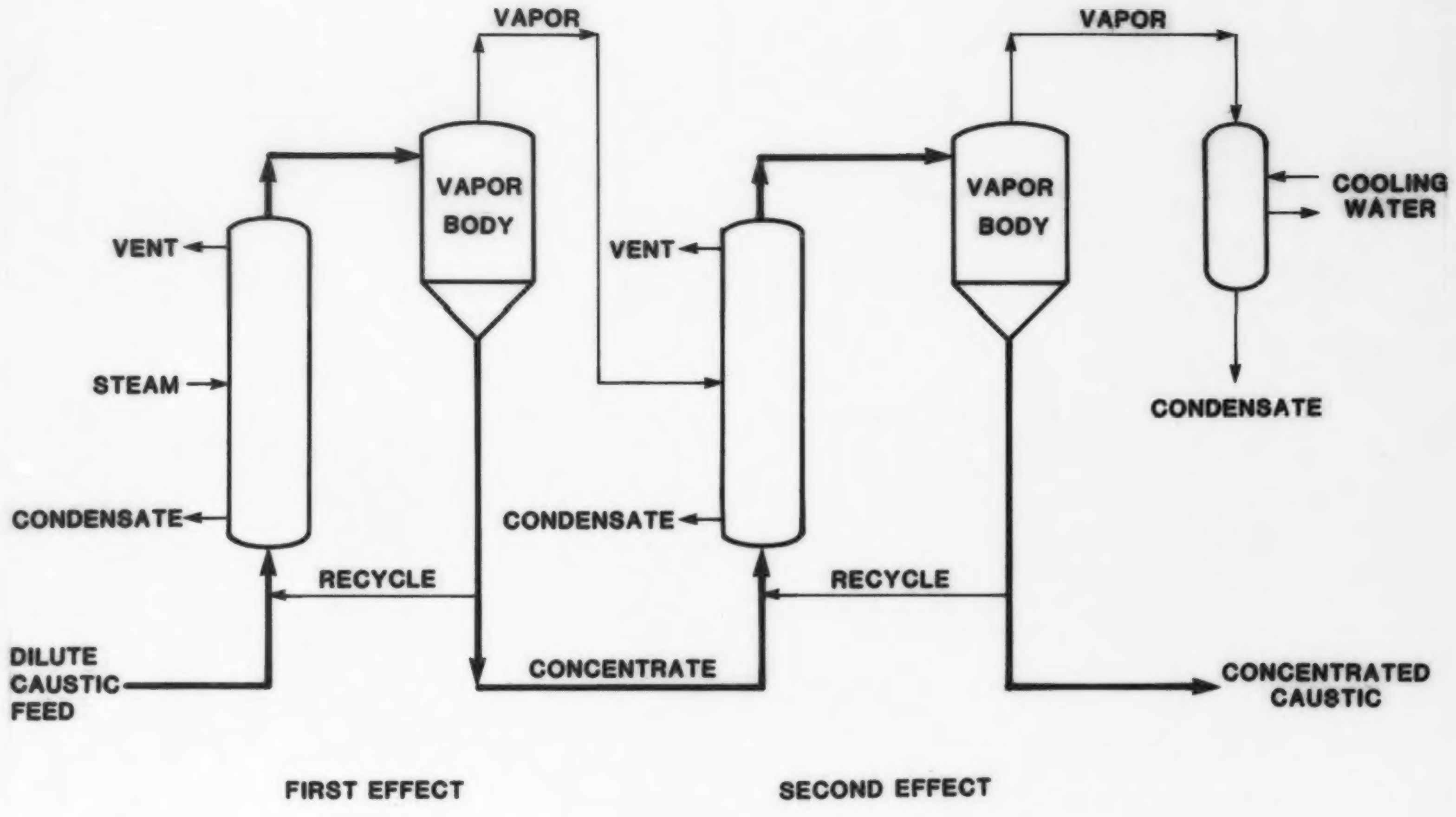

VAPOR
VAPOR
VAPOR
BODY
VAPOR
BODY
COOLING
WATER
VENT
VENT
STEAM
CONDENSATE
CONDENSATE
CONDENSATE
RECYCLE
RECYCLE
DILUTE
CAUSTIC
FEED
CONCENTRATE
CONCENTRATED
CAUSTIC
FIRST EFFECT
SECOND EFFECT

FIGURE VII-2 SCHEMATIC OF DUAL EFFECT EVAPORATOR

triple-effect evaporator, for example, may approach a steam economy of 2.5 pounds of water per pound of steam. The savings due to steam economy must also be balanced against the increased capital costs of additional effects. The costs of evaporation equipment are discussed further below.

Another method for achieving improved steam economy is through a vapor compression evaporator in which the vapor is compressed so it will condense at a high enough temperature to allow for efficient use of the heat in the same evaporator. This method has seen application for treating cooling water blowdown and chemical process water but has not been applied for caustic recovery because of the boiling point rise characteristics of the caustic solution and the inability to concentrate to as high a solids content as multiple-effect systems.

The heat required for caustic evaporation is the sum of the following:

Heat to raise the feed to the boiling point
Latent heat of vaporization
Heat of concentration
System heat losses

The overall heat transfer rate is proportional to the heating surface area, heat transfer coefficient (which in turn depends on solution properties, evaporator type, degree of fouling), and the mean temperature difference between the heating medium and the boiling liquid. An evaporator can be selected on the basis of optimizing a heat transfer "coefficient" in terms of BTU per hour per degree per dollar of installed cost. Values for heat transfer coefficients are presented in the following section on design.

Design Criteria

There are several types of evaporators encountered in the market. These include forced circulation, short tube vertical, long tube vertical, and horizontal tube. The vertical types can be found in configurations for falling film, rising film, and recirculating. Forced circulation and long tube vertical types are appropriate for caustic solutions due to their ability to tolerate the corrosiveness and foaming tendency of the caustic solutions.

The long tube vertical (LTV) is normally the cheapest per unit of capacity. It consists of a one-pass vertical shell and tube heat exchanger discharging into a relatively small vapor head. The large heating surface in one body helps in handling large evaporation loads. The LTV requires high headroom, depending on tube length, which can be up to 35 feet. The floor space requirement is relatively low.

Heat transfer coefficients for the LTV are highly variable and dependent on temperature differences. For high temperature differences, the rising film configuration is appropriate, and for small temperature differences and low temperature operation, the falling film configuration is recommended. Heat transfer coefficients range from 150 to 750 BTU/(hr)(sq ft)(°F) for fairly dilute solutions, as encountered with mercerization wastewater (4 to 5 percent caustic). The best coefficients are found at higher boiling temperatures (220 to 240 °F).

The forced circulation (F.C.) evaporator uses a pump to ensure circulation past the heating surface. This gives the advantage of better handling of viscous solutions which may be encountered in the latter effects of a multiple-effect evaporator. The capital and operating costs are relatively high because of the pumping arrangement. High heat transfer coefficients are achievable, particularly if some boiling occurs in the tubes; values range from 450 to 650 BTU/(hr)(sq ft)(°F), with the higher value at boiling temperatures near 220°F.

The following factors are influential in the selection of a proper evaporator design.

- Feed solution characteristics of viscosity, foaming tendency, corrosiveness, scaling and salting tendency, solids content.
- Prevention of fouling problems; ease of maintenance.
- Product quality and its effect on materials of construction and hold-up time.
- Prevention of splashing losses.

- Prevention of entrainment losses.
- Provision for condensers and vent systems.

Feed Solution Characteristics and Fouling Prevention. For caustic recovery from mercerization wastewater, viscosity varies with the temperature and concentration, such that the latter effects of a multiple effect system may need to consider F.C. as opposed to the generally acceptable LTV. In most cases for caustic recovery at textile mills, however, the final caustic concentration is not expected to exceed 35% by weight, so the final viscosity will likely not merit the use of F.C. Both F.C. and LTV can handle the foaming and corrosion of typical mercerization wastewater, though maintenance programs must recognize these potential problems. Scaling and salting are usually prevented by keeping the evaporating liquid in contact with any crystallized solid.

The solids content of mercerization wastewater normally requires both pre- and post-filtration to prevent fouling, clogging, and other maintenance problems, as well as provide a high quality concentrate. Prefiltration is accomplished with pressure cartridge filters or vibrating screens; post-filtration generally employs cartridge filters.

Product (Caustic) Quality. The primary consideration is that the caustic be free of solids, and it has already been mentioned that settling and filtration are required. The factors of hold-up time and special construction materials are not critical in the case of caustic recovery.

Accessories. Splashing losses and entrainment losses are generally minimized by a baffle system to control the flow of the rising vapor-liquid mixture.

Condensers (barometric or surface) and vent systems are typically included as evaporator accessories to condense the vapor from the last effect and to vent off non-condensable gases that may impede heat transfer.

Optimization. The goal of an evaporator is to provide the necessary amount of satisfactory product for the lowest total cost. Detailed economic analyses may include some of the following items:

- Initial steam pressure vs. cost or availability.
- Final vacuum vs. water temperature, water cost, heat transfer performance, and product quality.
- Number of effects vs. steam, water, and pumping costs.
- Distribution of heating surface between effects vs. evaporator cost.
- Evaporator type vs. cost and continuity of operation.
- Materials of construction vs. product quality, tube life, evaporator life, and cost.
- Corrosion, erosion, and power consumption vs. tube velocity.
- Down time for repairs.
- Operating labor and maintenance requirements.
- Method of feeding and use of heat recovery.
- Size of recovery heat exchangers.
- Possible withdrawal of steam for use elsewhere.
- Entrainment separation requirements.

As a general rule, total cost is most significantly affected by the number of effects or total square footage of evaporator surface. The optimum number of effects increases with an increase in steam costs or plant size for better heat recovery (Ref. 3).

A simplified method for minimizing costs in a multiple effect evaporator is to equalize the ratio of area to temperature difference ($A/\Delta T$) for all effects if cost per square foot (Z) is constant. If Z is variable, then $AZ/\Delta T$ should be equal for all effects (Ref. 3).

Another general rule, based on operating experience in the textile industry, is that at least a two percent caustic feed is required for recovery to be cost effective.

FACTORS LIMITING TECHNICAL FEASIBILITY

The only factor that has been identified as affecting the technical feasibility of this recycle technology is the ability to segregate the mercerization wastewater. This is required so that other processing chemicals and impurities do not enter the concentrated caustic.

ECONOMIC ANALYSIS

Capital Cost

Figure VII-3 presents a capital cost curve based on costs compiled in the EPA BAT survey of the textile industry. The costs represent actual installed costs for evaporation at several textile mills, updated to June 1983 prices. The costs are based on the dual- and triple-effect evaporators commonly used in this application. The data are plotted as capital cost versus product mercerized.

Operating Cost

The bulk of the operating costs for caustic evaporation is due to the use of steam to induce evaporation. Labor and maintenance costs, except on very small systems, are typically only a few percent of the steam costs. For estimating purposes, a value of one pound of steam can be used to evaporate two pounds of water. Alternately, a value of 15 lb steam/lb caustic recovered can also be used for estimating.

Baseline Economics

A typical size system (150,000 lbs fabric/day) was selected to determine the cost effectiveness, or payback period, for this recycle technology. The economic analysis for this baseline case is presented in Table VII-1. The assumptions used in developing these costs are shown in Table VII-2.

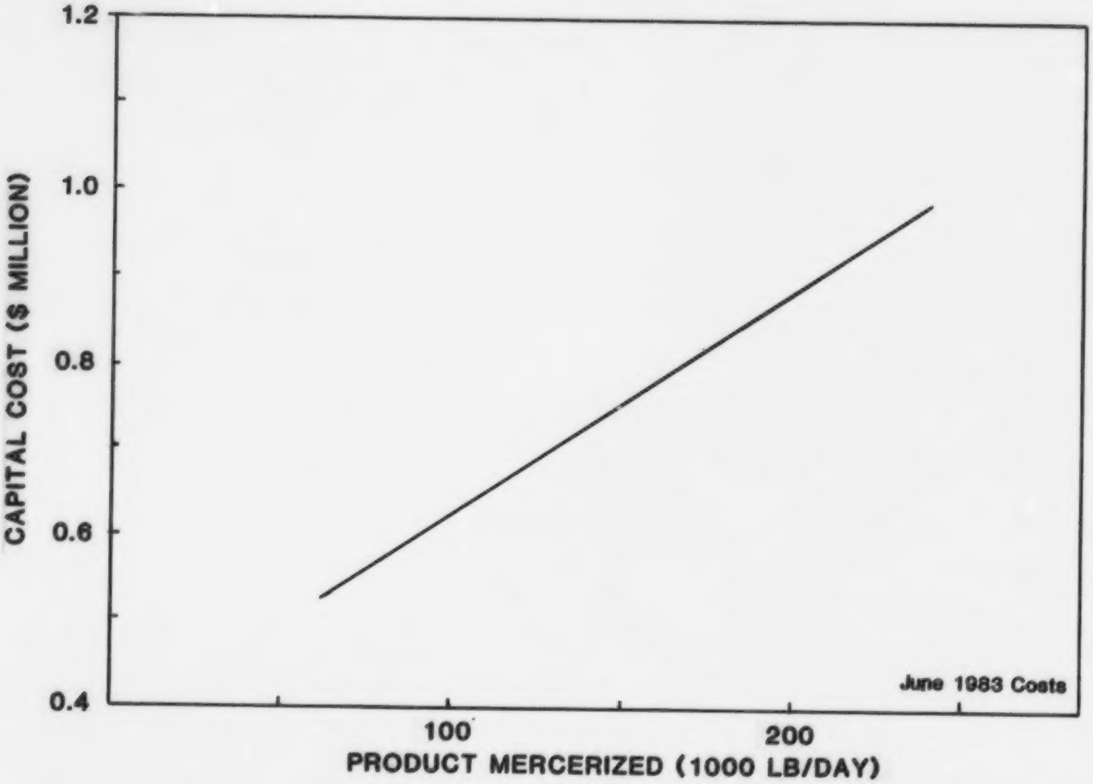


FIGURE VII-3 CAUSTIC RECOVERY CAPITAL COST

TABLE VII-1
BASELINE ECONOMICS
CAUSTIC RECOVERY BY EVAPORATION

Capital Cost	150,000 lb fabric/day		$ 750,000
Yearly O&M Costs			
Labor	1 man-year	$ 20,000	
Materials	2% of capital	15,000	
Steam	578,000 lb/day	867,000	
Subtotal			$ 900,000
Yearly Savings			
Water & Sewer	0.15 mgd	$ 45,000	
Energy	115×10^6 BTU/day	139,000	
Caustic Recovery	52,000 lb/day	2,340,000	
Subtotal			$2,524,000
Net Yearly Savings			$1.624,000
Payback Period	$750,000/$1,624,000/yr =	0.46 yr = 5½ months	

TABLE VII-2

BASIS FOR ECONOMIC ANALYSIS
CAUSTIC RECOVERY BY EVAPORATION

Mercerizing Production	150,000 lb fabric/day, 300 days/yr.
Water Use	1 gal/lb fabric
Wastewater	150,000 gpd
Caustic Concentration in Mercerizing Wastewater	4%
Caustic Concentration for Reuse	35%
Value of Caustic	$300/ton
Cost of Steam	$5/1,000 lb steam
Steam Utilization	1 lb steam evaporates 2 lb water
Water Savings	$0.50/1,000 gallons
Sewer Use Savings	$0.50/1,000 gallons
Energy Savings (hot water)	$4/million BTU, recycled water is 100°F hotter than plant water

Factors Affecting Economics

The primary factor influencing the economics of caustic recovery is the concentration of caustic in the mercerizing wastewater. A secondary factor is the existence of heat exchangers at the mill in question. These are examined in more detail below.

Concentration of Caustic in Mercerizing Wastewater. Although the evaporation efficiency may vary according to the particular system installed, a reasonable estimate for steam utilization in a triple-effect evaporator is that one pound of steam will evaporate two pounds of water. The unit cost of steam will also vary, but it is imperative that the amount of steam per pound of caustic recovered by kept to a minimum for economical operation. Therefore, the higher the concentration of caustic in the wastewater, the more cost effective the system will be. This is illustrated in Figure VII-4 where the effects of various caustic concentrations on the baseline case are shown. Minimizing washwater use and countercurrent washing are two methods in use at many finishing mills whereby caustic concentrations of up to 5 percent have been achieved.

Existence of Heat Exchangers. Many textile mills have already installed heat exchangers to recover energy from their hot wastewater. In such mills, the energy benefit from recycle of evaporator condensate will be smaller. As shown in Table VII-1, however, neglecting the energy savings causes only a small decrease in annual savings (about 10 percent). The effect on the payback period is thus small.

CURRENT APPLICATIONS

The installed system investigated at Mill W-3 feeds a double-effect evaporator 30 to 35 gpm of a dilute (4 to 5 percent by weight) caustic solution from the mercerization process. A vibrating screen is installed prior to the evaporator. The evaporator

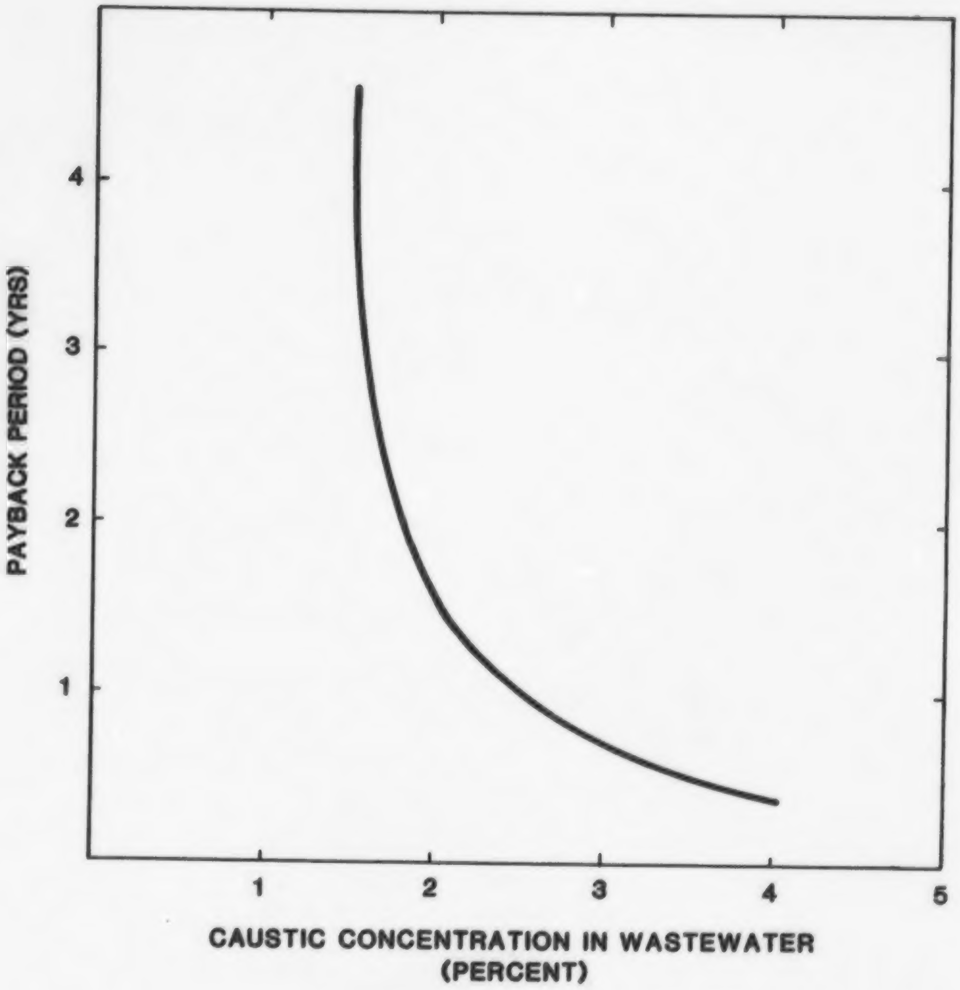


FIGURE VII-4 EFFECT OF CAUSTIC CONCENTRATION ON PAY BACK PERIOD

concentrates the solution to 35 percent caustic and recovers caustic at an overall rate of 80 percent. During November 1981, 304,000 pounds of caustic were recovered from the 360,000 pounds used by the mill. The system has been operating successfully for ten years.

A list of full-scale applications of evaporation for caustic recovery in the textile industry, as identified in the EPA BAT survey, is provided below:

Abney Mills
American & Efird Thread (Mt. Holley plant)
Burlington (Society Hill and Klopman-Altavista plants)
Cone Mills (Carlisle plant)
Cranston Print Works (Webster and Fletcher plants)
Dan River Mills (Danville plant)
Dixie Yarns (Chattanooga plant)
Fabrics America (Concord plant)
Fieldcrest Mills (Salisbury plant)
J. P. Stevens (Delta 3 plant)
Kendall (Bethune plant)
M. Lowenstein (Rock Hill and Lyman plants)
Milliken Service Company (Magnolia plant)
Riegel Textiles (Trion plant)
Santee Print Works
Springs Mills
Thomaston Mills
Threads, Inc. (Gastonia plant)
United Merchants & Manufacturers (Clearwater plant)
West Point Pepperell (Opelika plant)
Wilmington Finishing Company

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2. Conway, R. A. and R. D. Ross. Handbook of Industrial Waste Disposal, Van Nostrand Reinhold Company, 1980.

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4. U.S. Environmental Protection Agency. Development Document for Effluent Limitations Guidelines and Standards for the Textile Mills Point Source Category, EPA 440/1-82/022, NTIS No. PB83116871, September 1982.

SECTION VIII
DYEBATH AND BLEACH BATH RECONSTITUTION

INTRODUCTION

Textile preparation and dyeing can be performed by either continuous or batch processes. Continuous processes are generally used for long runs of sheeting or other woven fabrics. Batch processing continues to be used on the majority of textile products due to its advantages of short-run capability, versatility, and easy control.

Batch processes, however, generally use and discharge much larger quantities of water and auxiliary chemicals than continuous processes. This results in more severe pollution problems as well as higher unit processing costs.

An alternative to the discharge of exhausted batch processing baths is to save the bath, analyze it for remaining chemical/dye quantities, and then reconstitute the bath for further use. In this manner, a single processing bath can be reused many times before being discharged. Figure VIII-1 depicts a general schematic of reconstitution.

This method of reuse has potential for being applied to dyebaths and bleach baths. With dyebaths, the potential for significant auxiliary chemical savings makes dyebath reconstitution an economically attractive alternative to conventional batch dyeing. Recent research and applications have shown that dyebath reconstitution is applicable to a large amount of the batch dyeing being performed today, and not only to the repeat shade dyeing applications where it has been practiced in the past. With bleach baths, particularly with synthetic fibers, many cycles of reuse can result in significant water savings.

ENVIRONMENTAL BENEFITS

Little or no information is available in the literature to document the environmental benefits of using dyebath or bleach bath reconstitution. And the information that is available is generally limited to water use savings.

A limited amount of wastewater sampling was conducted during Phase II of this project at Mill Y-4. This mill was using both dyebath

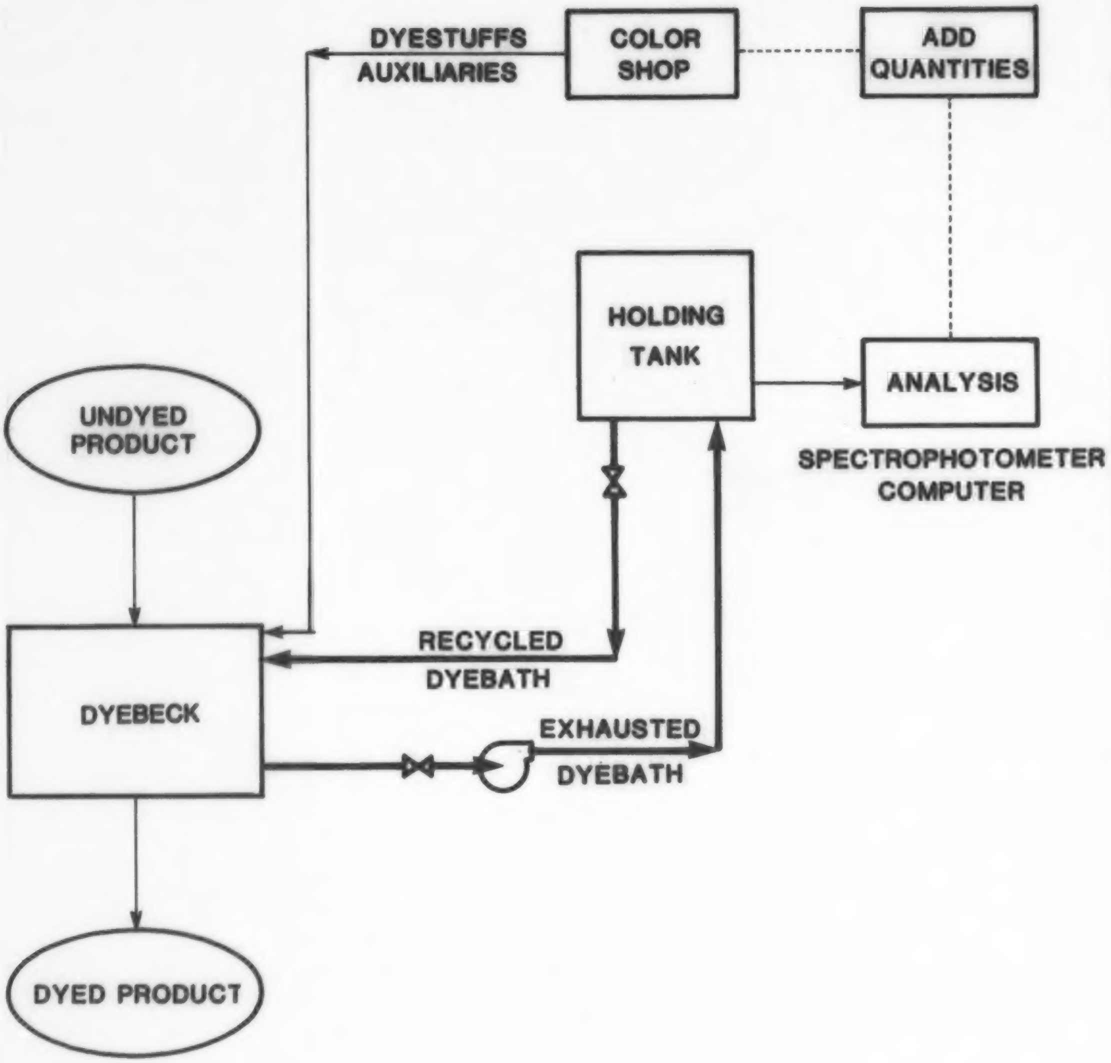
DYESTUFFS
AUXILIARIES
COLOR SHOP
ADD QUANTITIES
HOLDING TANK
ANALYSIS
SPECTROPHOTOMETER
COMPUTER
UNDYED PRODUCT
RECYCLED
DYEBATH
DYEBECK
EXHAUSTED
DYEBATH
DYED PRODUCT

FIGURE VIII-1 RECONSTITUTION PROCESS SCHEMATIC

and bleach bath reconstitution on a limited scale. A single grab sample was taken of an exhausted dyebath after 11 cycles of reuse. This was compared to the average pollutant concentrations found in the exhausted baths from conventional batch dyeing:

	Conventional	Reconstituted
BOD	410 mg/l	1,500 mg/l
COD	1,180 mg/l	5,700 mg/l
TS	9,500 mg/l	6,210 mg/l

Assuming a dyebath volume of about 2,000 gallons, 11 conventional dyeings would produce 75 pounds of BOD. The single reconstitution series discharge would produce only 25 pounds of BOD, a reduction of 67 percent. More substantial data need to be collected to quantify these reductions. In terms of wastewater volume, 11 conventional dyebath drops would generate 22,000 gallons of wastewater. The single drop from the reuse series would generate 2,000 gallons. Of course, the water volume and pollutant loads from rinsing would be comparable for both conventional and reconstituted dyeings.

PROCESS DESCRIPTION AND DESIGN CRITERIA

The reconstitution process can be thought of as consisting of four parts:

1. Saving the just-exhausted process bath.
2. Analyzing the bath for residual chemicals.
3. Reconstituting the bath.
4. Reusing the bath for subsequent processing.

These four items are discussed in more detail below. The discussion is directed at dyeing, but is also applicable for bleach bath reconstitution.

Saving the Exhausted Bath

Two basic alternatives are available for saving the exhausted dyebath. The dyebath can be pumped to a holding tank, while the product is rinsed in the same machine in which it was dyed. Then as soon as the rinsed product is removed, the dyebath can be returned to the dye machine for the next dyeing cycle.

Alternatively, the dyed product can be pulled from the exhausted dyebath and moved to another machine for rinsing. This alternative eliminates the need for holding tanks and pumps, but requires additional product handling and a spare machine to use for rinsing.

A critical factor in either scheme is the temperature of the exhausted dyebath. At some mills, the hot dyebath after dyeing can be pumped (or the product pulled) without any damage to the product. In other mills, the dyebath must be cooled to prevent product streaking. Cooling can be done with non-contact cooling water (i.e., heat exchangers), or with contact cooling water (overflow or cool-down rinsing). The use of contact cooling water will dilute the dyebath, thereby increasing the quantities of chemicals required for reconstitution. Alternatively, bump-and-run dyeing techniques can be used wherein the dye liquor temperature is initially raised to the dye strike temperature and held for a short period, and then allowed to drift downward throughout the remainder of the normal dye cycle time. This drifting is designed to allow the dyebath to cool to an acceptable temperature so that overflow rinsing is no longer required. Bump-and-run dyeing has been successfully introduced at a number of mills, thereby eliminating the need for overflow rinsing. This technique also results in significant energy savings (Reference 11).

Dyebath Analysis

The exhausted dyebath consists of water, unexhausted dyestuffs, and unexhausted auxiliary chemicals. In general, about 10 percent of the water used in dyeing is lost through evaporation or is carried off in the wet, dyed product. This water must be made up before the next dyeing cycle.

Most auxiliary chemicals do not exhaust to an appreciable degree during the dyeing process. Thus, the makeup quantity is also about 10 percent, due to carryoff on the product. Certain auxiliaries, however, will exhaust or be partially depleted during dyeing. Generally, it is sufficient to estimate the degree of exhaustion and the quantity needed to replenish the bath.

The unexhausted dyestuffs, however, must be analyzed to determine the exact quantities remaining in the dyebath. This is to ensure that the proper shade is achieved in the next dyeing cycle. The analysis is performed with a spectrophotometer. With a single dyestuff, the absorbance of the dyebath is related to the concentration of the remaining dyestuff by the modified Lambert-Beer equation:

$$A = KC$$

where A = absorbance of the dyebath solution
K = an experimentally derived constant
C = dyestuff concentration.

In a mixture of several dyestuffs (e.g., three), the absorbance is the sum of the absorbances due to each dyestuff:

$$A = K_1C_1 + K_2 C_2 + K_3 C_3$$

In a mixture of three dyestuffs, the absorbance is determined at three separate wavelengths, thereby giving three equations of the type shown above. The three equations can be solved, thereby giving the concentrations of the three dyestuffs.

Several complications can arise in performing this analysis. Some dyestuffs (e.g., disperse dyes) are not water soluble and must be extracted into an organic solvent for analysis. Benzene, toluene, and octanol have been used as solvents.

In some cases, a correction must be made for the absorbance due to background sources (e.g., fiber tinting, auxiliary chemicals, etc.). In such cases, a "blank" dyebath is prepared (without dyes). The absorbance characteristics of the "blank" dyebath and the background K values are then determined. When analyzing a mixture of three dyebaths, the absorbance would then be determined at four separate wavelengths, giving four equations to be solved. Solving these equations would give four concentrations: one for each of the three dyestuffs, and one for the "background dye."

Reconstituting the Bath

Reconstituting the bath consists of adding back the quantities of water, auxiliary chemicals, and dyestuffs needed for the next dyeing cycle. As noted previously, water is added to replace any lost through evaporation or in the prodct. Auxiliary chemicals are also added in proportion to the amount of water added. Any auxiliary chemicals that exhaust during dyeing are added to make up for such exhaustion losses. In general, these quantities can be estimated and do not require exact analysis. Dyestuff add quantities are determined by substracting the quantities present in the exhausted dyebath (as determined above) from the recipe quantities for the next shade to be dyed.

Reusing the Bath

The major difference in reusing a dyebath is that the starting temperature is generally higher than that of fresh water. This starting temperature should be tested and evaluated so that spotting and levelness problems do not occur in the reuse dyeings. In general, the loss of heat during storage, and the cooling due to makeup water are sufficient to drop the dyebath temperature to a safe level.

Design Criteria

The following general design criteria are given for a reconstitution system:

- Storage tank volume should hold a single dye beck volume.
- A single storage tank can serve several dyebecks depending on the dyeing schedule and cycle times.
- A visible-light, single beam, grating spectrophotometer is sufficient for dyebath analysis.
- A desk computer is often employed to compute the dye concentrations in the exhausted dyebath. With such systems, dye recipes are also stored on the computer so that the computer can calculate the add quantities of dyes and auxiliary chemicals for the next dyeing. With such a system, the reconstitution process is simplified so that most dyehouse personnel can readily analyze and reconstitute dyebaths.

Some preparatory work needs to be done to successfully implement reconstitution at a textile mill. Phase III of this project will detail the work performed at one mill to implement this technology. This will include experimental work to determine dye/absorbance data, laboratory scale reuse dyeing, design of the reconstitution system including analytical and computing equipment and software, costs, results of reuse dyeings, and more substantial environmental data.

FACTORS LIMITING TECHNICAL FEASIBILITY

Textile dyeing is a complicated process and consequently there are many factors that may affect the implementation of dyebath reconstitution. The most significant factors are listed below:

- Dyebath reconstitution is most successful when all of the color shades to be dyed in a reconstitution series are formulated from the same dyestuffs. For example, the same three dyestuffs should be used to dye all shades in a given series of reuse dyeings. This greatly simplifies the analysis and calculation of dyestuff and quantities.
- Reconstitution has been successfully demonstrated with acid, basic, direct, disperse, and sulfur dyes. A special split bath technique is required with reactive dyes. The first bath or dyeing bath is the portion that is covered and reused. The second bath, or fixing bath, must be kept separate from the dyeing bath to prevent hydrolysis of the unexhausted dyestuff. Such hydrolysis would render the unexhausted dyestuff unusable in the next dyeing cycle.
- Dyebath reconstitution works best with single shade dyeings (repeat dyeings) and with shade sequences that progress from light to dark. Progressing from a dark shade to a light may also be feasible, but sometimes the residual dyestuff from the dark shade is more than the recipe amount for the lighter shade.
- Maximum cost savings and environmental benefits accrue from long reconstitution series. However, production schedules may limit the number of dyeings that can be performed before a new

series must be started or before conventional dyeing must be resumed on a given dye machine. In addition, the buildup of impurities in the recycled dyebath can limit the number of cycles feasible. A cost analysis is presented later in this section to determine the effects of shorter numbers of cycles on the cost effectiveness of reconstitution.

- Certain dyestuffs may have absorption peaks at wavelengths that are too close to permit accurate analysis by spectrophotometric measurements at only a few wavelengths. In such cases, a more detailed analysis (at up to 16 different wavelengths) must be made to accurately determine the quantities of residual dyestuffs in the exhausted dyebath. A more complex solution technique is then required to solve for the residual dyestuff concentrations.
- Although most auxiliary chemicals do not exhaust onto the fibers being dyed, a few do exhaust. In such cases it is necessary to estimate the degree of exhaustion (either based on manufacturer's data, or on laboratory tests) so that the appropriate quantities can be added back prior to the next dyeing cycle. In rare occasions, an auxiliary chemical may consit of two or more components that exhaust at differing rates. In such cases it is necessary again to determine the exhaustion rate of each component so that the proper amounts may be added back.
- It is generally not possible, nor is it desirable to commit all the dyebecks in a mill to reconstitution. The potential savings are still very large even if only half the becks are committed. This level of commitment also allows a mill to maintain its flexibility in meeting production schedules.

ECONOMIC ANALYSIS

Capital Cost

Capital costs for a reconstitution system can be estimated based on the unit costs presented below (June 1983 dollars):

Spectrophotometer	$3,000
Miscellaneous Labware	1,000
Desk Computer	5,000
Holding Tank (2,000 gal)	6,000
Pump, Controls (200 gpm)	4,000
Piping, Valves, Screen (per tank)	6,000

Larger tanks, pumps, and piping will be required for large dyebecks, such as in the carpet finishing sector of the industry. Not included in the above costs are the costs of lab testing and other preparations prior to instituting the reconstitution program.

Operating Costs

Operating costs for reconstitution systems include the power for dyebath pumping, pump maintenance costs, and miscellaneous labware costs. No additional manpower requirements are included for dyebath analysis, since this takes only a few minutes per cycle. A conservative estimate of operating costs is $2,000 per beck.

Baseline Economics

The economics of dyebath reconstitution will vary depending on the value of auxiliary chemicals used, the type of dyestuffs, liquor ratios used in dyeing, and numerous other factors. To establish a starting point for determining the economic feasibility of dyebath reconstitution, the following model case was examined. A typical dyehouse containing 10 dyebecks at 1,500 gallons each converts five becks to dyebath reconstitution. Holding tanks are installed to store the exhausted dyebath while the fabric is rinsed. Dyebath analysis is by a spectrophotometer and desk computer. Table VIII-1 shows the results of the economic analysis. Table VIII-2 lists the assumptions

TABLE VIII-1

BASELINE ECONOMICS
DYEBATH RECONSTITUTION

Capital Cost	
Spectrophotometer	$ 3,000
Computer	5,000
Labware	1,000
Holding Tanks (5 @ 2,000 gal)	30,000
Pumps, Controls (5 @ 2,000 gal)	20,000
Piping, etc.	30,000
Total Capital Cost	$ 89,000
Yearly Operating Costs	$ 10,000
Yearly Savings	
Water Use (30,000 gpd)	$ 3,750
Sewer Use (30,000 gpd)	3,750
Energy (22.5 mm Btu/day)	22,500
Auxiliary Chemicals	75,000
Total Savings	$105,000
Net Yearly Savings	$ 95,000
Payback Period	11 months

TABLE VIII-2

BASIS FOR ECONOMIC ANALYSIS
DYEBATH RECONSTITUTION

Dyehouse has 10 becks, 5 committed to reconstitution

Each beck processes 5 batches/day, 250 day/year

Batch size is 750 lb

Dye liquor ratio is 2 gal/lb

Dyebath is reused 5 times prior to discharge

Auxiliary chemical savings are 2¢/lb fabric for 4 cycles

Dyebath is returned at 150°F compared to 60°F water supply

Energy costs are $4/mm Btu

Water costs are $0.50/1,000 gallons

Sewer use fees are $0.50/1,000 gallons

used in developing the costs. As shown in Table VIII-1, the resulting payback period for this model case, 11 months, is promising. Typical payback periods for this technology range from six months to two years.

Factors Affecting Economics

Five factors have been identified that have a large effect on the economic feasibility of dyebath reconstitution: dye liquor ratio, value of auxiliary chemicals, series length, overflow rinsing, and the use of the hot-pull technique.

Dye Liquor Ratio. The capital cost of dyebath reconstitution equipment (tank, pump, and piping) is largely dependent on the volume of dye liquor to be handled. While the savings that result from reconstitution are somewhat dependent on the dye liquor volume (e.g., energy, water, and sewer use savings), the major savings are in auxiliary chemicals costs; these costs are more dependent on the quantity of product dyed. Therefore, the payback period for dyehouses with high dye liquor ratios (e.g., carpet mills) is generally longer than than for dyehouses with low ratios. This is illustrated in Figure VIII-2 where the effect of varying the dye liquor ratio in the model case on the payback period is shown.

Value of Auxiliary Chemicals. The model case assumed an auxiliary chemical cost savings of two cents per pound of product. While this is a fairly typical value, each dyehouse must be examined in terms of actual chemical costs to determine the actual payback period. Figure VIII-2 shows the effect of varying the chemical value on the model case payback period.

Series Length. The length of reconstitution series (number of dyeings prior to dumping the dyebath) has an effect on the payback period. However, as Figure VIII-2 shows, very long series lengths are not required to achieve an acceptable payback period. In the model case, a series of five dyeings produces a payback period of under one

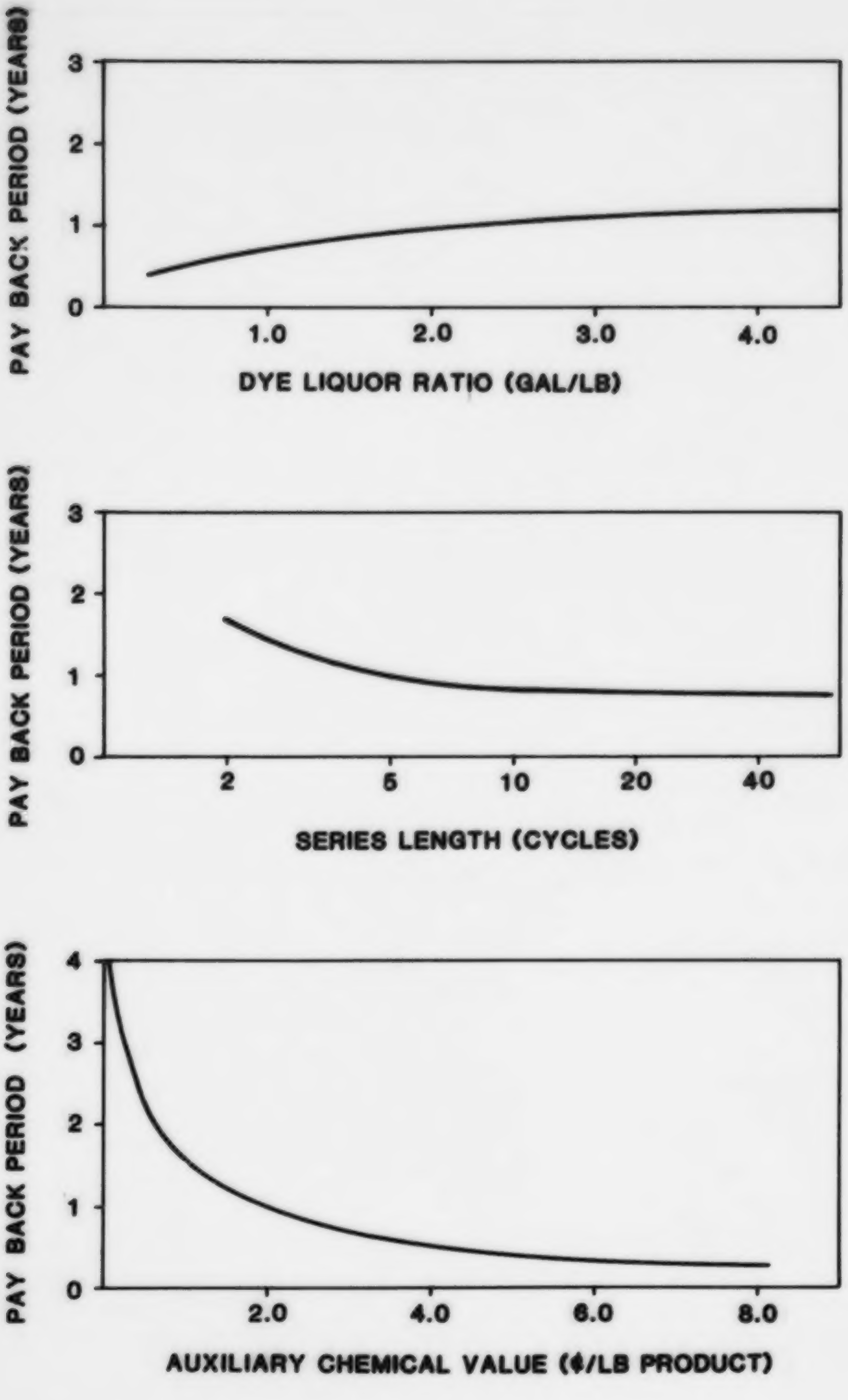

FIGURE VIII-2 EFFECT OF VARIABLES ON RECONSTITUTION ECONOMICS

year. Extending the cycle length to 10 or 20 cycles produces only marginal gains. This can be understood by realizing that a series of five reduces the discharge of dyebaths by 80 percent as compared to conventional dyeings (only one of five baths is dumped with reconstitution). With a series length of ten, the savings are only increased to 90 percent (one of ten baths is dumped).

Overflow Rinsing. The use of an overflow rinse dilutes the exhausted dyebath. The amount of dilution can be significant depending on the desired temperature drop and the temperature of the cooling water. The remaining auxiliary chemical value can be used to estimate the effect of an overflow rinse. For example, if the undiluted, exhausted bath contained auxiliary chemicals valued at 2¢/lb, and the use of an overflow rinse diluted the dyebath to half of its original concentration, remaining auxiliary chemical value would be equivalent to 1¢/lb, causing the model case payback period to increase from 11 to 19 months. Therefore, it is valuable to investigate alternatives to overflow rinsing, such as non-contact cooling or bump-and-run dyeing.

Hot Pull. The use of hot-pull, or removing the fabric from the hot, exhausted dye liquor for rinsing in another machine, can greatly reduce the capital cost of reconstitution since tanks, pumping, and piping are no longer required. The use of this technique, however, is based on the availability of a spare beck that can be used for rinsing and the ability to pull the product at an elevated temperature without affecting product quality.

Phase II Studies. The effects of these variables can be seen in the results of engineering studies of implementing dyebath reconstitution at three mills during Phase II of this project.

Mill	Liquor Ratio (gal/lb)	Auxiliary Chemical Value (¢/lb product)	Payback Period (years)
W-4	0.9	1.0	0.5
C-2	4.5	2.0	1.1
Y-4	2.1	1.1	0.6

Mills W-4 and Y-4 presented similar situations, with dye liquor ratios of 1- to 2-gal/lb and a recoverable auxiliary chemical value of about 1¢/lb. Both mills showed a payback period of about half a year, although Mill Y-4 was able to reconstitute dyebaths without the aid of a spectrophotometer/computer, based on assumed dyestuff exhaustion rates. This savings in equipment costs lowered the payback period to about four months. At Mill C-2, a high dye liquor ratio, typical of carpet dyeing, resulted in higher capital costs. These costs were offset somewhat by a greater value for auxiliary chemicals. The net result was a projected payback period of just over one year.

CURRENT APPLICATIONS

Six mills that are practicing, or have recently practiced, full-scale reconstitution were identified during this project. Table VIII-3 summarizes these applications, and they are discussed in more detail below. Table VIII-3 also lists many of the pilot scale and lab-scale studies that have been performed.

At the three woven fabric mills, a variety of fabrics was dyed using dyebath reconstitution. A small mill dyeing woven Nomex fabric instituted a reconstitution system at a cost of about $15,000. Due to the high cost of auxiliary chemicals for dyeing Nomex, the reuse of dyebaths saved about 25 cents/lb of fabric in chemical costs. The annual savings were expected to be in excess of $110,000.

A velvet manufacturer successfully uses dyebath reconstitution. Direct dyestuff add quantities are based on estimates; no anlysis of the exhausted dyebath is conducted.

A woven fabric dyer had used dyebath reconstitution to replenish vat and sulfur dyebaths used in dyeing cotton fabrics. No cost data is available on this application, and due to product changes, it is no longer in use.

TABLE VIII-3
RECONSTITUTION APPLICATIONS

FULL-SCALE APPLICATIONS

Product	Fiber	Dyestuff	Dye Machines
Woven Fabric	Nomex	Basic	Jet
Woven Fabric	Cotton	Direct	Reel
Woven Fabric	Cotton	Vat/Sulfur	Jig
Ladies' Hosiery	Nylon	Disperse	Paddle/Drum
Carpet	Nylon	Acid	Beck
Yarn	Acrylic	Basic	Package

PILOT OR LAB SCALE APPLICATIONS

Product	Fiber	Dyestuff	Dye Machines
Woven Fabric	Polyester	Disperse	Jet
Woven Fabric	Cotton, Pol/Cot	Reactive	Beck
Woven Fabric	Nylon/Cotton	Acid/Direct	?
Ladies' Hosiery	Nylon	Disperse	Paddle/Drum
Men's Hosiery	Nylon	Acid	Paddle
Men's Hosiery	Acrylic	Basic	Paddle
Carpet	Nylon	Acid	Beck
Carpet	Nylon	Disperse	Beck
Carpet	Polyester	Disperse	Beck
Yarn	Polyester	Disperse	Package

Successful dyeings of up to 41 batches have been conducted at a ladies' hosiery mill. Auxiliary chemical savings for runs of 14 to 17 batches were 34 percent, with dye savings of 18 percent. The capital cost of expanding dyebath reconstitution from the one machine to six of the mills' dye machines was $28,000, and the payback period was estimated to be about two years.

At the carpet mill, full-scale trials at a single dyebeck showed successful dye runs of up to 13 dyeings before discharging the dyebath. Auxiliary chemical savings were close to 60 percent, and dye savings ranged from 0 to 7 percent. The estimated payback period for expanding dyebath reconstitution to eight of the mill's 14 becks was 6.6 months, and the estimated capital cost was $230,000.

At the yarn mill, full-scale trials at a single package dye machine resulted in dyeings of up to 30 cycles before dyebath discharge. Ten cycle dyeings are most common. At this mill, bleach bath reconstitution is also practiced, with runs as long as 10 or more cycles. No difference in the ratio of acceptable to unacceptable dyeings has been noted with reconstitution as compared to conventional dyeing. Dyestuff addition is based on rule-of-thumb estimates of 95% dyestuff exhaustion. No dyebath analysis is conducted.

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SECTION IX

DYE WASTEWATER DECOLORIZATION BY OXIDATION

INTRODUCTION

Exhausted dyebath and rinse waters from batch dyeing can be treated by chemical oxidation with chlorine. This treatment removes a substantial amount of color from the wastewater, allowing it to be reused for dyebath makeup water and initial rinse water. Auxiliary chemicals in the wastewater are not substantially affected during treatment. Therefore, some benefit is gained by reducing the amount of auxiliary chemicals needed for dyebath makeup. The use of this technology also results in water use and energy use savings, as well as lower sewer use charges due to the reduced wastewater discharge.

This recycle technology has promise in all types of textile finishing mills (woven fabric, knit fabric, hosiery, carpet, stock and yarn) where batch dyeing is performed. This technology could also be applied to rinsewater from continuous dye ranges, but the lack of high auxiliary chemical content in the wastewater makes the technology uneconomical. Specific factors affecting the use of this technology are addressed below.

ENVIRONMENTAL BENEFITS

Reductions of 70 to 80 percent in dye wastewater discharge have been reported at several mills with full-scale chlorine oxidation systems. No information is available on the decrease in pollutant discharge resulting from recycle, but it also is expected to be significant. A potential drawback for this recycle technology is the possibility for chlorinated organics to be formed and discharged. No studies or data are presently available to assess this potential problem.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description

Figure IX-1 is a process schematic for this wastewater recycle technology. As shown, wastewater from the dyeing operation is

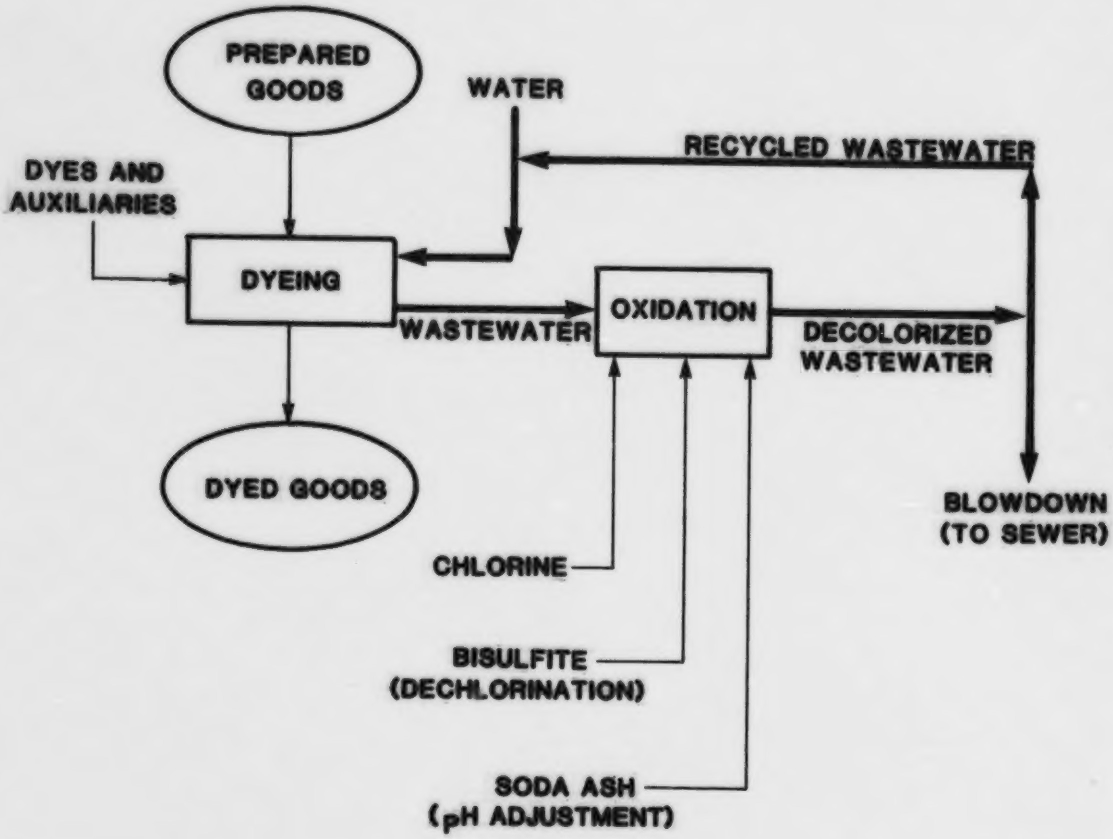
PREPARED GOODS
WATER
RECYCLED WASTEWATER
DYES AND AUXILIARIES
DYEING
OXIDATION
WASTEWATER
DECOLORIZED WASTEWATER
DYED GOODS
BLOWDOWN (TO SEWER)
CHLORINE
BISULFITE (DECHLORINATION)
SODA ASH (pH ADJUSTMENT)

FIGURE IX -1
OXIDATION PROCESS SCHEMATIC

treated with chlorine to decolor the wastewater, and then with bisulfite (or sulfur dioxide) to remove residual chlorine. Soda ash (or caustic) is used to adjust the pH during treatment and prior to reuse. A portion of the water is blown down to the sewer to prevent the buildup of impurities in the recycled water. The recycled water is used for dyebath makeup and for initial rinses following dyeing. Final rinsing is generally done with fresh water. The treated water usually retains a pale straw-yellow color at typically used chlorine dosages, but this residual color generally has no detrimental effect on dyeing or rinsing.

Design Criteria

Chemical oxidation is a process in which the oxidation state of a substance is increased. The purpose of oxidation in water and wastewater treatment is one of converting undesirable chemical species, such as unspent dyestuffs, to species that are neither harmful nor otherwise objectionable. In the case of dye wastewater decolorization, as with most other chemical oxidation applications, it is neither necessary nor practical to carry the oxidation process to absolute completion. In actual textile applications, oxidation is used to decrease the molecular weight of dye molecules by attacking amide and other linkages of the molecules, thereby destroying chromophoric groups and decoloring the wastewater.

Chlorine gas is bubbled through textile dye wastewater and instantly forms hydrochloric acid and hypochlorous acid in accordance with the following generalized equation:

$$Cl_2 + H_2O \longrightarrow HCl + HOCl$$

Recommended chlorine dosages range from 25 mg/l to 100 mg/l, depending on the dyestuff type and its concentration in the wastewater. Bench- and pilot-scale testing are needed to determine dosages and other parameters, such as treatment time, for a particular application.

Typical treatment times are about 10 to 40 minutes. For example, acid dyes require only 2 to 7 minutes to decolorize, whereas disperse dyes take 25 to 35 minutes to decolorize. Fiber reactive dyes decolor about as rapidly as acid dyes, but require higher chlorine dosages and a higher reaction temperature. Direct dyes, like the disperse dyes, require longer contact times for decolorization. In addition to the time for decoloring, a few minutes are required for dechlorination and pH adjustment.

For treating acid dyes, it is desirable to decolorize under acidic conditions, preferably at a pH of 5-6. As the pH increases above neutral, the decolorization reaction slows down so that at a pH of 9.0 and above, substantially little or no decolorization occurs. For this reason, commercial liquid chlorine is not the preferred decolorizing agent. It contains about 15 percent sodium hypochlorite, which yields a major proportion of sodium hydroxide. In addition, it is costly and unstable, and yields only a minor amount of free chlorine. Similar pH effects are noticed for decoloring other classes of dyestuffs with chlorine, although disperse dyes will decolor at a higher pH (8 to 8.5). Liquid caustic or soda ash is commonly used as a buffer. Sodium bisulfite or sulfur dioxide may be used as an antichlor to neutralize or destroy any excess chlorine remaining after decolorization. An existing full-scale operation is known to have used 0.5-1.5 lbs soda ash/ 1,000 gal and 0.3-1.0 lb sodium bisulfite/1,000 gal wastewater.

Figure IX-2 shows a detailed schematic of the dye wastewater treatment system. The system size is based on the peak flow per minute multiplied by a small safety factor. Equalization prior to the actual oxidation system is helpful in that it reduces flow variations and provides for gradual changes in the characteristics of the dye wastewater being treated. Treatment tank capacity will vary depending on the dye class being treated at a particular mill. For acid dye wastewater, a treatment capacity equal to one hour average flow is sufficient. Storage capacity for return to the mill can be designed equal to the volume anticipated in two hours of average flow. The system should be designed to return the water with as little cooling down as possible. The system described above generally returns decolorized water at a temperature of 100°F to 120°F. From 10 to 30 percent makeup is required in the system to offset evaporative losses and blowdown to the sewer.

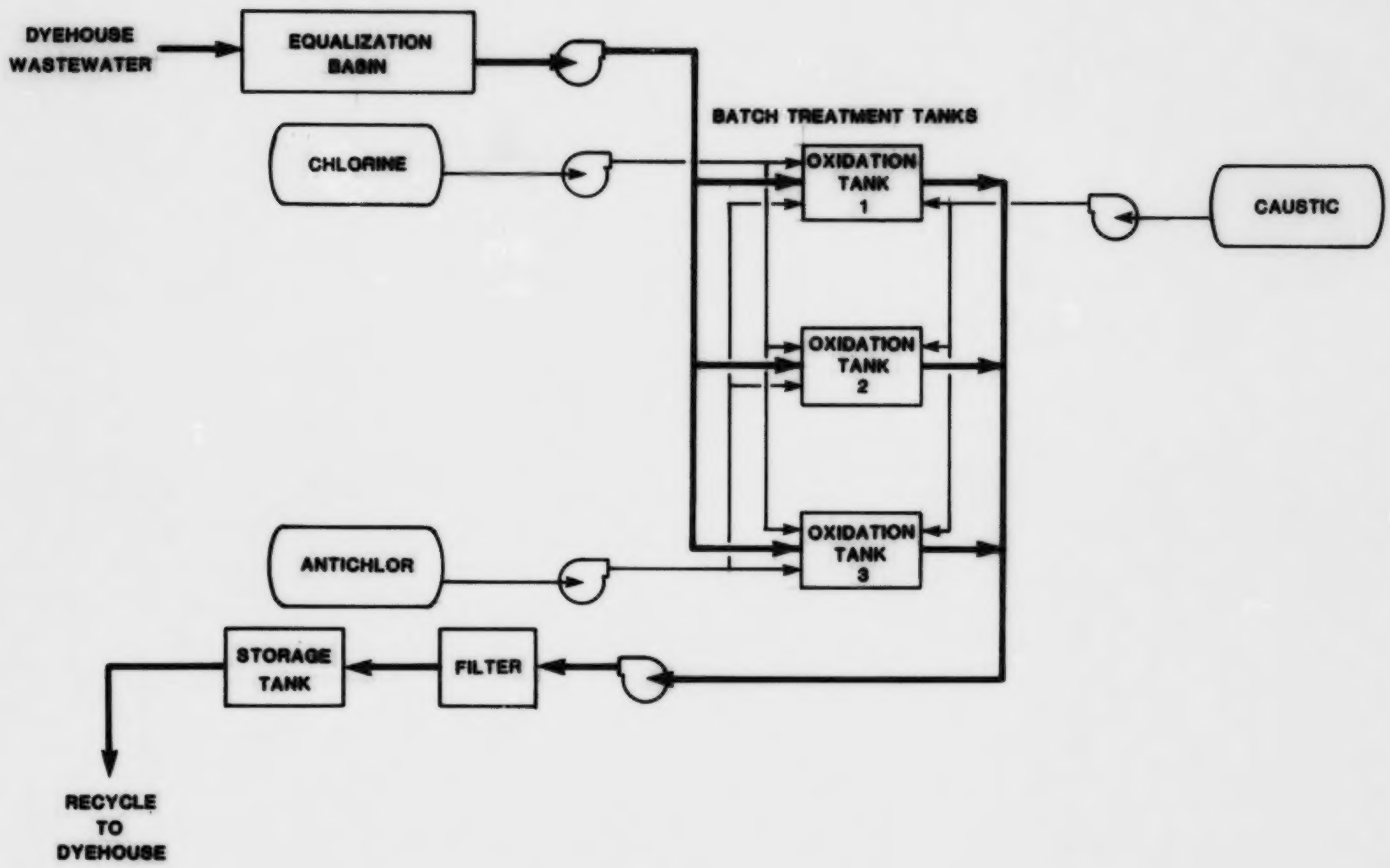
DYEHOUSE WASTEWATER
EQUALIZATION BASIN
CHLORINE
BATCH TREATMENT TANKS
OXIDATION TANK 1
OXIDATION TANK 2
OXIDATION TANK 3
CAUSTIC
ANTICHLOR
STORAGE TANK
FILTER
RECYCLE TO DYEHOUSE

FIGURE IX-2 OXIDATION TREATMENT SYSTEM SCHEMATIC

A Georgia firm, Textile Systems, Inc. (TSI), has a patent on continuous flow systems enabling textile dyehouse wastewater reuse using chlorine oxidation. Their system consists of a control center, stainless steel treatment tanks, holding tanks, a chemical feed system, and a filtration system, in addition to required pumps, piping and valves, and other hardware. The operation of this type of system is described below. Dye wastewater from an equalization pit is pumped into open treatment tanks. During this filling operation, chlorine is added. Diffused air is injected to mix the tank, and liquid caustic or soda ash is added to maintain proper pH. After mixing, sodium bisulfite or sulfur dioxide gas is used as an antichlor, and the treated wastewater is pumped to storage tanks for reuse in the dyehouse.

FACTORS LIMITING TECHNICAL FEASIBILITY

Two specific factors have been identified as affecting the technical feasibility of this recycle technology: the dyestuff used in dyeing, and the ability to segregate the dyeing wastewater.

Dyestuff Use

Several considerations regarding dyestuff use are important in evaluating the feasibility of oxidation for decolorization. First, the dye molecule must be amenable to oxidation by chlorine. Certain dyestuffs have been developed to resist the effects of chlorine residuals in the city water used for dyeing. These dyestuffs may also prove resistant to the dosages of chlorine used in the oxidation treatment system. Bench scale tests are, therefore, required to determine if the dye wastewater at a particular mill can be decolored by chlorine.

Second, the type of dyestuff used will affect the chlorine dose and reaction time required for decoloring. The following general statements can be made regarding the major dyestuff classes:

Dye Class	Ease of Decoloring	Typical C_{l2} Dose (mg/l)	Reaction Time
Acid	Easy	25 to 50	Short (2-7 min)
Basic	Moderate	50 to 75	Short
Direct	Moderate	50 to 100	Long
Disperse	Easy	50 to 75	Long (25-30 min)
Fiber Reactive	Difficult	50 to 75	Short

Bench scale tests are required for determining the actual reaction time and chlorine dose required for decoloring. Such tests were performed at three mills during Phase II of this project. At Mill C-2, a chlorine dose of 50 mg/l and a reaction time of 15 minutes were sufficient to decolor wastewater from acid dyeing of nylon carpet. ADMI color values were reduced from 700 to 800 units in the untreated wastewater to approximately 300 units following treatment. This residual color is the "straw yellow" color referred to previously.

At Mill Y-4, a chlorine dose of 100 mg/l was needed to reduce color levels in basic dye wastewater from a range of 17,200 to 26,000 ADMI units to a range of 410 to 700 units. A 15-minute reaction time was sufficient.

At Mill W-4, limited testing showed that the disperse dye wastewater was decolored, but optimum chlorine dosages and reaction time were not determined.

In addition to the ability of the dyestuffs to be decolored by oxidation, an additional consideration is that only a single class of dyestuff should be involved in the recycle system. This is due not only to the differences in decoloring rates and chlorine dosages, but also to the auxiliary chemicals used in dyeing. Since these auxiliary chemicals will be partially recovered and reused in the recycled water, they should be compatible with all classes of dyeing performed. For example, a carpet mill that dyes 90 percent of its production with acid dyes and the remaining 10 percent with disperse dyes will normally segregate and discharge the disperse dyeing wastewater to the sewer. Thus, only the acid dyeing wastewater is treated and recycled.

Segregation of Dyeing Wastewater

Segregation of the dyeing wastewater from other types of wastewater, e.g., preparation wastewater, is also required. Sizing compounds and fabric impurities (oils, etc.), as well as metals, gums, and paste constituents, can interfere with the oxidation process and are undesirable in the recycled water.

ECONOMIC ANALYSIS

Capital Cost

Figure IX-3 presents a capital cost curve for various size dye wastewater oxidation systems. The curve is based on cost quotations from Textile Systems Incorporated for their package treatment system (reaction tanks, chemical feed systems, storage tanks, piping, controls), with allowances for installation, site work, wastewater equalization, and engineering added as follows:

Package Treatment System	Base Cost
Installation	8% of base
Equalization	5% of base
Site Work	20% of base
Contingency	10% of base
Engineering	7% of base

Operating Cost

Figure IX-3 also shows yearly operating and maintenance costs (power, labor, and parts) for the oxidation treatment system. These costs do not include chemical costs. At a typical chlorine dose of 50 mg/l, the following are approximate chemical costs for the treatment of one million gallons of wastewater. These costs should be adjusted for the actual dosages required and local unit prices.

	Chemical Dose		Unit Price	Treatment Cost
Chemical	mg/l	lb/10^6 gallons	\$/lb	\$/10^6 gallons
Chlorine	50	420	0.10	42.00
Caustic	100	830	0.27	224.00
Sulfur Dioxide	50	420	0.18	76.00
			Total	$342.00

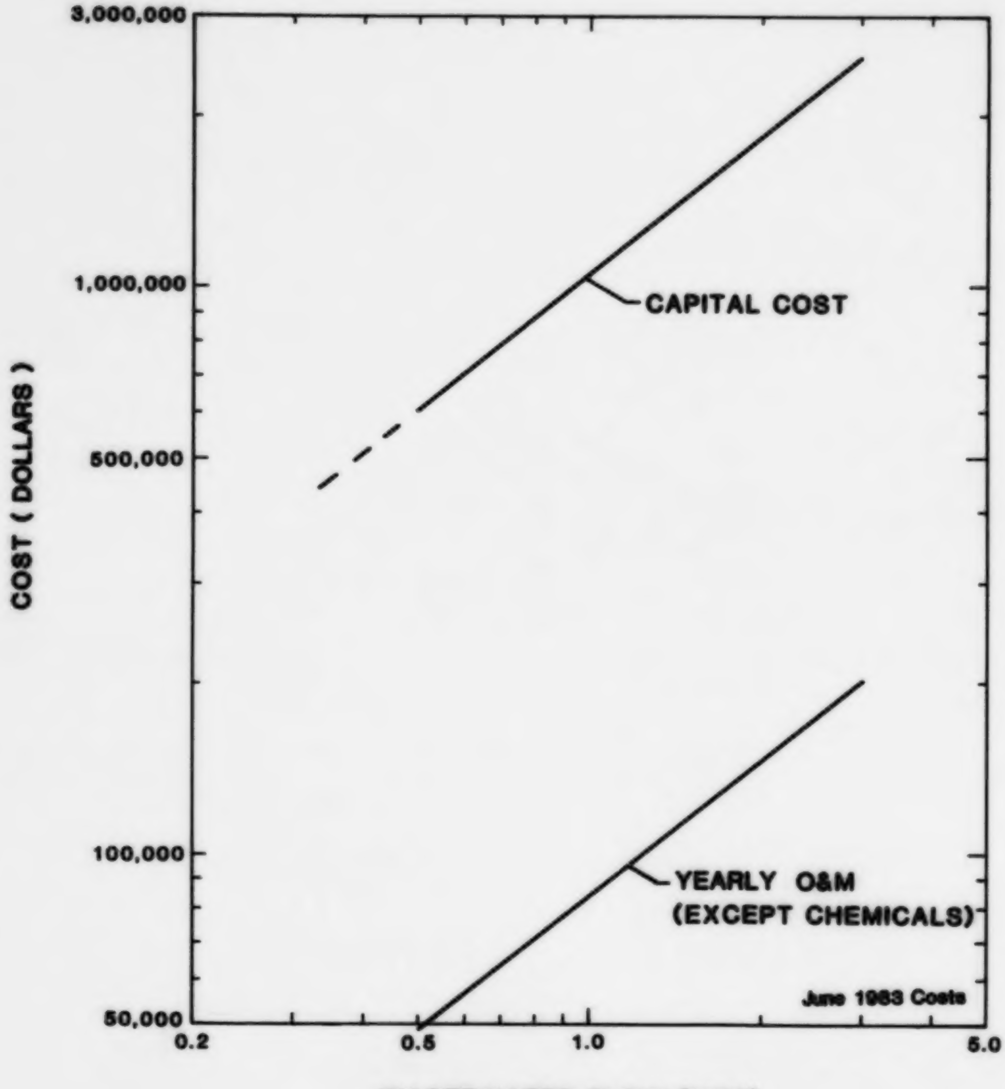

FIGURE IX-3 DYE WASTEWATER CHLORINATION SYSTEM COSTS

Baseline Economics

As just discussed, various factors such as the dyestuff used in dyeing have an effect on the sizing and capital cost of the treatment units as well as on the chemical requirements for treatment. To provide a starting point for determining the economics of this technology, a baseline or model case was examined. A typical size system (1 mgd) was selected to determine the cost effectiveness, or payback period, for this recycle technology. The detailed economic analysis for this model case is presented in Table IX-1. The assumptions used in developing these costs are shown in Table IX-2. A payback period of approximately three years is seen for this technology under these circumstances. The typical range of payback periods is from three to five years.

Factors Affecting Economics

Various factors can influence the economics of oxidation as a recycle technology. These factors include:

- Dyestuff Used (chlorine dose and reaction time)
- Dyeing Water Use (liquor ratio)
- Value of Recoverable Auxiliary Chemicals
- Existence of Heat Exchangers at Mill
- Need for Waste Segregation

Each of these is examined in more detail below.

Dyestuff Used.

The class of dyestuff in the wastewater to be decolored will affect either the chlorine dosage required or the reaction time, or both. A larger or smaller chlorine dose will also require differing amounts of caustic for neutralization and sulfur dioxide for dechlorination. However, since the treatment chemical costs are a relatively small part of the overall operating costs and annual savings for the oxidation system, the payback period is relatively insensitive to changes in the dosage of chlorine required for decoloring. This is demonstrated in Figure IX-4(a) where the effects of varying chlorine dosages on the model case presented previously are shown.

TABLE IX-1

BASELINE ECONOMICS
DYE WASTEWATER DECOLORIZATION BY OXIDATION

		Dollars
Capital Cost	1 mgd system	1,000,000
Yearly O&M Costs		
Labor and Materials		85,000
Chlorine	330 lb/day	8,000
Caustic	670 lb/day	45,000
SO_2	330 lb/day	15,000
	Subtotal	153,000
Yearly Savings		
Water Use	0.7 mgd	87,500
Sewer Use	0.7 mgd	87,500
Energy	10^8 Btu/day	100,000
Auxiliary Chemicals	$0.01 per lb fiber	250,000
	Subtotal	525,000
Net Yearly Savings		372,000
Payback Period		2.7 years

TABLE IX-2

BASIS FOR ECONOMIC ANALYSIS
DYE WASTEWATER DECOLORIZATION BY OXIDATION

Dyeing	100,000 lb fiber/day for 250 day/year
Water Use	10 gal/lb fiber
Wastewater	1 mgd
	10% evaporation loss, 20% blowdown
Auxiliary Chemicals	$0.02/lb fiber used, 50% recovered
Treatment	50 mg/l chlorine (330 lb/day) at $0.10/lb
	100 mg/l caustic (670 lb/day) at $0.27/lb
	50 mg/l SO_2 (330 lb/day) at $0.18/lb
	10% evaporation loss, 20% blowdown
Water Savings	$0.50/1000 gallons
Sewer Use Savings	$0.50/1000 gallons
Energy Savings	$4 per million Btu based on 40°F heating cost savings for 0.3 mgd flow (dyebath makeup) and 0°F for remainder (rinsewater)
Power Cost	$0.05/kwh

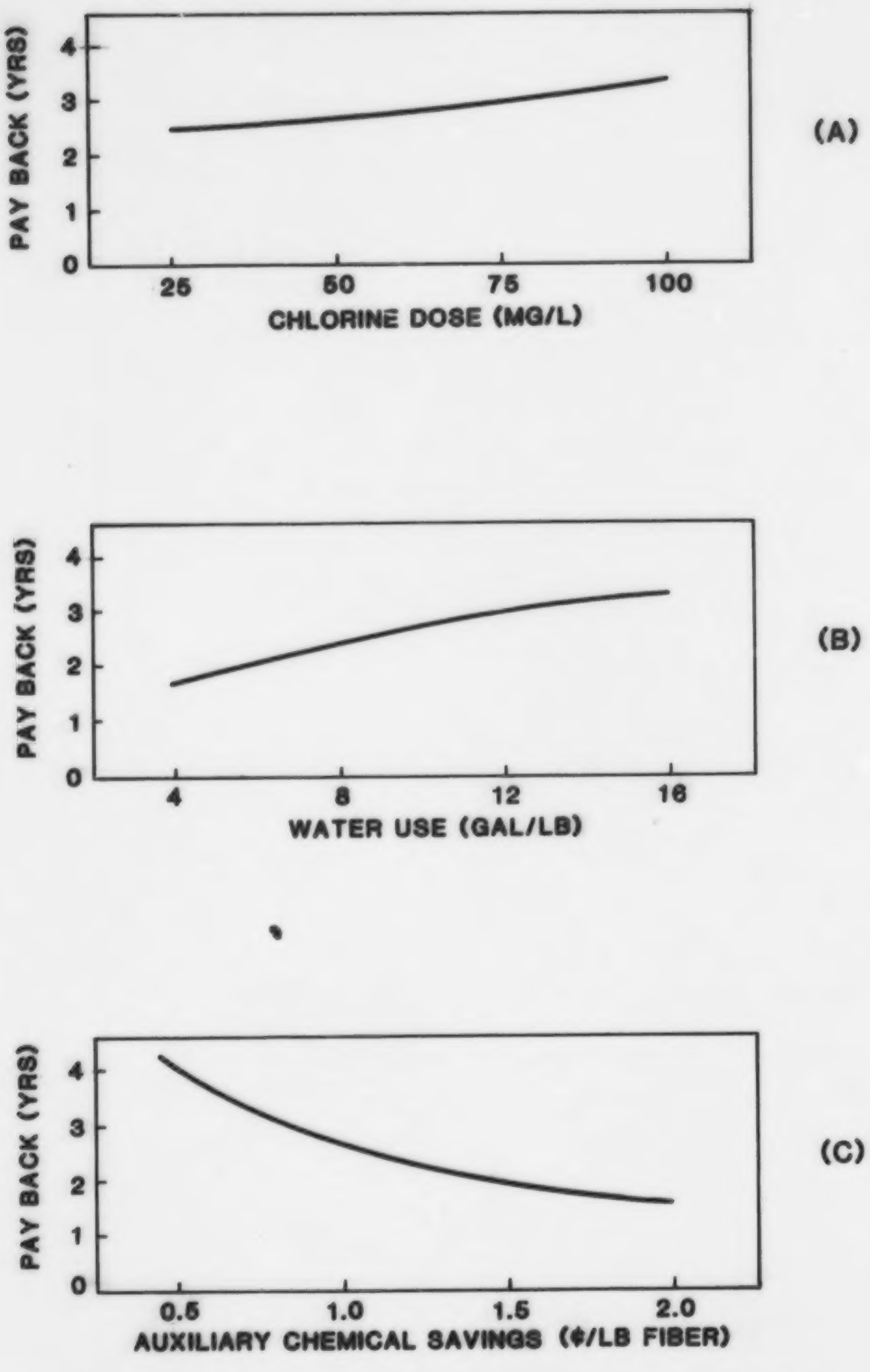

FIGURE IX-4 EFFECT OF VARIABLES ON CHLORINATION ECONOMICS

The reaction time required for decoloring has a more significant effect. For dyestuffs requiring longer reaction times, such as disperse dyes, capital costs and payback periods are expected to be up to twice as long as for the model case.

Dyeing Water Use. The amount of water used in dyeing and rinsing will affect the sizing of the treatment systems needed for decoloring. Water, energy, and sewer use savings will also be affected. Figure IX-4(b) shows that the amount of water used in dyeing has a significant effect on recycle economics. Thus, mills with relatively high liquor ratios, such as carpet mills, will have relatively long payback periods for this recycle technology compared to mills with lower liquor ratios, such as woven or knit fabric finishers.

Value of Recoverable Auxiliary Chemicals. The value of recoverable auxiliary chemicals is the major benefit of this (and most other) recycle technologies. The model case was based on an auxiliary chemical use of $0.02/lb fiber with 50 percent recovered through recycle. Figure IX-4(c) shows the effect of different recoverable auxiliary chemical values on the model case payback period. As expected, the effect of this variable is large.

Existence of Heat Exchangers. Many textile mills have already installed heat exchangers to recover energy from their wastewater. In such mills, the energy benefit from recycle of wastewater will be negligible. Deleting the energy savings from the economic analysis for the model case results in an increase of one year in the payback period, to a total of 3.7 years.

Need for Waste Segregation. Many textile mills have combined sewers for preparation and dyeing wastewaters. At these mills, segregation of the dyeing wastewater is necessary in order to use oxidation as a treatment/recycle technology. Further segregation of wastes, e.g., by dyestuff class, may also be required. The costs incurred for waste segregation must be included in the economic feasibility analysis for this recycle technology.

The effects of these variables can be seen in the economic analyses at the three mills where this technology was studied under Phase II of this project:

Mill	Cl_2 Dose (mg/l)	Reaction Time (min)	Water Use (gal/lb)	Auxiliary Chemical Savings (¢/lb)	Technology Payback Period
Y-4	50	10	4.4	1.1	2.5
C-2	50	10	13.5	2.0	3.0
W-4	100	30	4.5	1.0	4.7

Mills Y-4 and W-4 are comparable in terms of water use and the value of recoverable auxiliary chemicals. However, Mill W-4 uses disperse dyes. The longer reaction time requires a larger treatment system. The higher chlorine dose also increases capital costs. Hence, the resulting payback period is almost doubled from the 2.5 years shown at Mill Y-4.

Comparing Mills Y-4 and C-2, the higher recoverable auxiliary chemical value at Mill C-2 is more than offset by the much higher water use. The resulting payback period is thus slightly higher than at Mill Y-4. The detailed economic analyses for these mills are contained in the appendices.

CURRENT APPLICATIONS

Five full-scale applications of dye wastewater decoloring technology using chlorine are known to exist.

At Salem Carpet Mills in Chickamauga, Georgia, about 1 mgd of wastewater from acid dyeing of nylon carpet are treated and recycled. Disperse dyeing wastewater and wastewater from the Kuster dye range are bypassed to the sewer. Savings of 45 percent in energy use, 40 percent in auxiliary chemicals, and 80 percent in water use have been reported by this mill.

Hollytex Carpets in City of Industry, California, is a similar application of this technology for wastewater recycle from acid dyeing of nylon carpet. Seventy percent of the mill's wastewater is recycled.

Tropical International Enterprise in Miami, Florida, employs this recycle technology for recycling up to 0.15 mgd from disperse dyeing of woven polyester fabric. Up to 96 percent of the dyebath wastewater is treated and recycled. Rinsing (scouring) water is not treated or reused.

Other known applications are North State Finishing in Lincoln, North Carolina, and an unidentified mill in Mexico.

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3. Perkins, W. S., J. F. Judkins, Jr., and W. D. Perry. "Renovation of Dyebath Water by Chlorination or Ozonation," Textile Chemist and Colorist, Vol. 12, Nos. 8-10 (August-October, 1980), pp. 182-272.

4. Textile Systems Incorporated. "Water Reclamation System," manufacturer's brochure.

5. United States Patent 3,807,947. "Leveling Acid or Direct Dyes with Chlorine Decolored Acid or Direct Dye Wastes," April 30, 1974.

6. United States Patent 3,927,965. "Direct and Acid Dyes with the Same Dye Chlorine Decolored as Leveller," December 23, 1975.

7. Water Control Systems, Inc. "Water Reclamation System," unpublished paper.

SECTION X

DYE WASTEWATER DECOLORIZATION BY GRANULAR ACTIVATED CARBON ADSORPTION

INTRODUCTION

Exhausted dyebath and rinse waters from batch or continuous dyeing can be treated with activated carbon to enable reuse. This treatment removes a substantial amount of the color and organics from the wastewater. Organic auxiliary chemicals are also generally removed during treatment, but inorganic auxiliary chemicals, such as buffers or salts, are not removed and thus can be reused in the recycled water used for dyebath makeup. The use of this technology also results in water use and energy use savings, as well as lower sewer use charges due to the reduced wastewater discharge.

Activated carbon adsorption can potentially be applied to all types of textile finishing mills (woven fabric, knit fabric, hosiery, carpet, stock and yarn) where dyeing is performed. Specific factors affecting the use of activated carbon adsorption as a recycle technology are addressed below.

ENVIRONMENTAL BENEFITS

The use of carbon adsorption for dye wastewater treatment should result in a reduction of 90 percent in dye wastewater discharge, allowing for 10 percent blowdown. An actual 80 percent reduction was reported at one full-scale installation. At that mill, very deep colored dyebaths were discharged to the sewer rather than treated. This was to keep the carbon from exhausting rapidly. No information is available on the decrease in pollutant discharge resulting from the treatment and reuse of dyeing wastewater, but this decrease is also expected to be significant, perhaps as high as 80 or 90 percent.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description

Figure X-1 is a process schematic for this recycle technology. Wastewater from dyeing is generally prefiltered or screened to remove

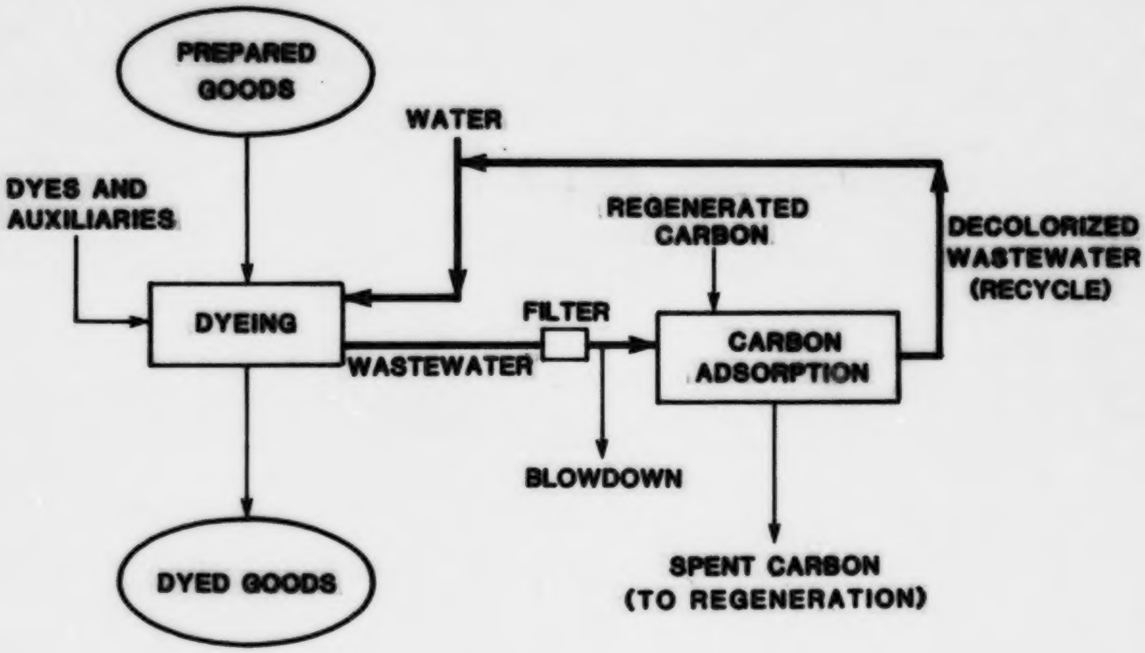
PREPARED GOODS
WATER
DYES AND AUXILIARIES
REGENERATED CARBON
DECOLORIZED WASTEWATER (RECYCLE)
DYEING
FILTER
CARBON ADSORPTION
WASTEWATER
BLOWDOWN
SPENT CARBON (TO REGENERATION)
DYED GOODS

FIGURE X-1
ACTIVATED CARBON PROCESS SCHEMATIC

lint and other coarse suspended solids. The wastewater is then passed through beds of activated carbon where dye molecules and other organic species are adsorbed onto the surface area of the activated carbon granules. The treated wastewater can then be recycled to the dyehouse. A blowdown (generally 10 percent of the wastewater flow) is used to control the buildup of impurities and dissolved salts in the recycled water. Virtually complete color removal can be achieved with activated carbon treatment systems. A more detailed flow schematic of the treatment system is presented in Figure X-2.

Design Criteria

The two major design criteria used in sizing activated carbon adsorption systems are the contact time and the carbon exhaustion rate. Several other process criteria, such as hydraulic loading rates, mode of operation (fixed bed, pulsed bed, upflow mode, downflow mode), and type of activated carbon used also affect the design of the treatment system.

Typical contact times for textile wastes range from 30 to 60 minutes. The design contact time at a full-scale system for treating and recycling carpet dyeing wastewater was approximately 42 minutes.

Typical carbon exhaustion rates for decoloring textile wastewaters range from approximately 0.1 to 10 lb carbon/1000 gallons wastewater, depending on the dyestuffs present, their exhaustion, and the presence of other organic auxiliary chemicals. Bench and pilot-scale tests are used to determine the actual expected exhaustion rate. The full-scale system noted above experienced a carbon exhaustion rate of 0.55 lb carbon/1000 gallons.

Typical hydraulic loading rates range from 2 to 10 gpm/ft^2 of carbon bed. Carbon bed dimensions generally are from 10 to 30 feet in depth, and up to 12 feet in diameter. The bed is contained in a steel shell that is coated to prevent corrosion and erosion. The carbon bed can be operated in one of several modes: fixed bed, pulsed bed, upflow or downflow, pressurized or open.

A fixed bed carbon adsorption column is run until the carbon is exhausted. At that time, the entire charge of carbon is removed and either replaced or regenerated. The wastewater flow in a fixed bed

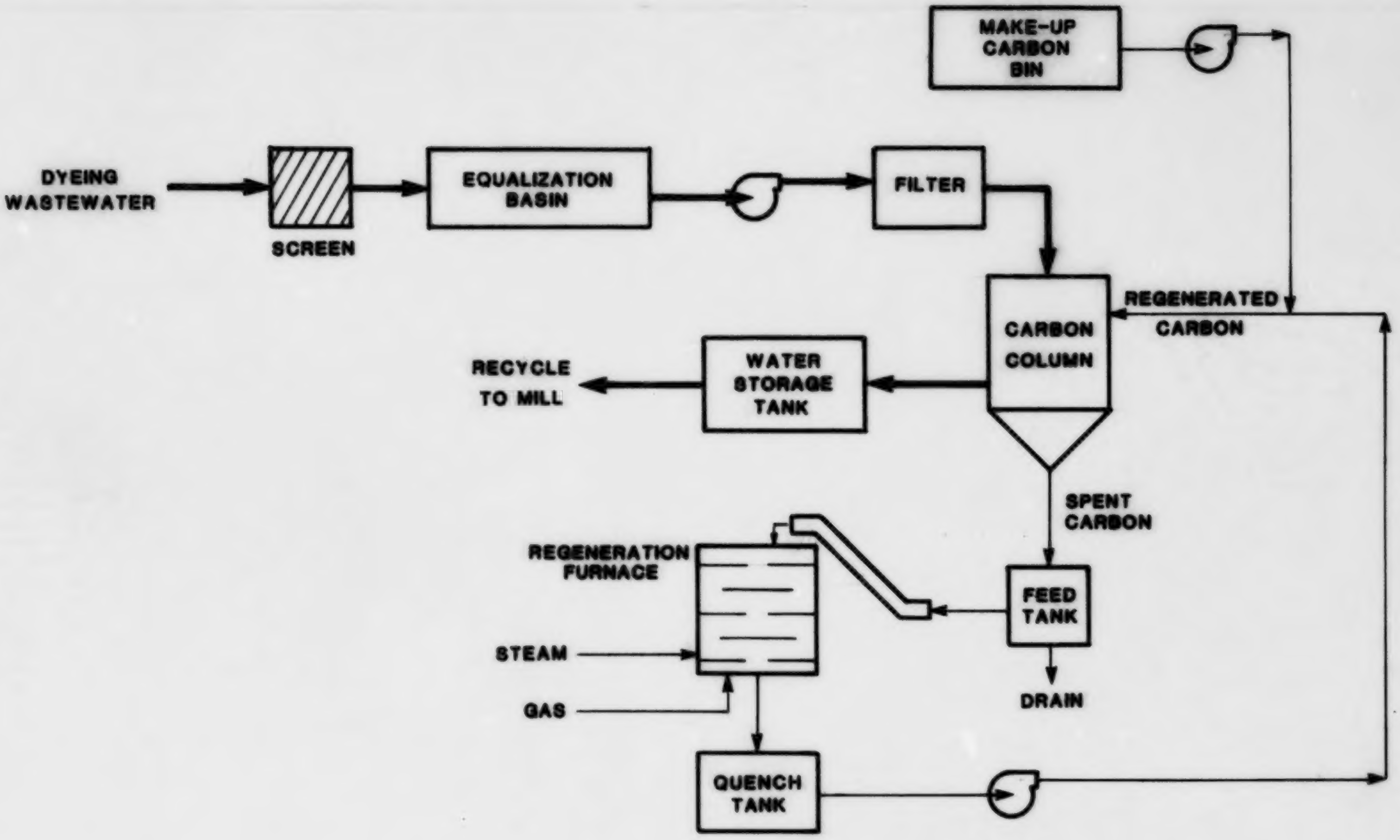
MAKE-UP CARBON BIN
DYEING WASTEWATER
SCREEN
EQUALIZATION BASIN
FILTER
CARBON COLUMN
REGENERATED CARBON
RECYCLE TO MILL
WATER STORAGE TANK
SPENT CARBON
REGENERATION FURNACE
FEED TANK
STEAM
GAS
DRAIN
QUENCH TANK

FIGURE X-2 CARBON ADSORPTION TREATMENT SYSTEM SCHEMATIC

adsorption system can be in either an upflow or a downflow mode. Most of the pilot scale tests of activated carbon systems at textile mills have been with fixed bed carbon columns operated in the downflow mode.

In a pulsed bed system, the carbon column is operated in an upflow mode; therefore the carbon at the bottom of the column is exhausted before the carbon at the top. A small portion of the carbon is periodically removed from the column bottom, and fresh carbon added at the top. The full-scale system referred to previously operated in this mode.

Periodically, the carbon beds must be backwashed with water to remove suspended solids that have been filtered from the wastewater. Backwash rates of 15 to 20 gpm/ft^2 are commonly used.

The relative advantages and disadvantages of the two most common modes, downflow fixed bed versus upflow pulsed bed, are summarized in Table X-1.

Bench-scale testing is a necessity to determine the optimum carbon type, contact time, and adsorption capacity. Batch testing is conducted to determine adsorption isotherms. The results of these tests identify the adsorption capacity and optimum carbon type. Continuous testing is then used to determine actual carbon bed service times and removal efficiencies. Both types of tests are used to evaluate a particular application of activated carbon adsorption technology.

Adsorber system configurations must be designed for the particular application. Typical configurations are: a) single bed (fixed or pulsed); b) two or more fixed beds in series; c) two or more fixed or pulsed beds in parallel; and other combinations of series/parallel operation depending on the required loads and removals.

Single beds are advantageous where carbon dosage is low and replacement costs are a minor operating expense, and additional capital costs cannot be justified by lower carbon makeup rates.

Series operation is advantageous for fluctuating influent concentrations and for more complete exhausting of the carbon (lower carbon makeup rate).

Parallel operation is advantageous for large flow rates, continuous operation, and for consistent overall effluent quality.

TABLE X-1
RELATIVE COMPARISON OF CARBON ADSORPTION SYSTEMS

	Downflow Fixed Bed	Pulsed (Moving) Bed
Height requirement	Low	High
Area requirement	High	Low
Operator attention	Low	High
Carbon fines in effluent	Low	High
Series operation	Feasible	Not Feasible
Internal inspection	Easy	Difficult
Suspended solids handling	Fair	Poor
Inlet wastewater pressure	Low	High
Capital cost	High	Low
Variability of effluent characteristics	High	Low

Spent activated carbon granules can be discarded, regenerated on-site, or regenerated off-site through a contract arrangement. Carbon regeneration techniques can be thermal, chemical, or biological, with thermal being the most popular to date.

Thermal regeneration is performed by multiple hearth furnaces, rotary kilns, fluidized bed furnaces, or transport reactors. Multiple hearth furnaces and rotary kilns are the most widely used. Chemical regeneration techniques include acid or base extraction, wet oxidation, chemical oxidation, and solvent extraction. Biological methods can be aerobic or anaerobic.

It is not economical to perform on-site regeneration unless furnace throughputs are very large, generally exceeding 1500 lb/day. Each application must consider the costs and performance of regenerated versus fresh carbon.

FACTORS LIMITING TECHNICAL FEASIBILITY

The essential factor that limits the technical feasibility of the activated carbon adsorption technique is the type of dye. Investigations show that it is effective for soluble dyes, such as acid, direct, basic, and reactive, but relatively ineffective for disperse, vat, sulfur, and pigment dyes.

The performance of thermally regenerated carbon is not as good as virgin carbon for low molecular weight dyes, because these are adsorbed on micropores that are reduced in thermal regeneration.

Biological regeneration is limited by the biodegradability of the adsorbed organics.

ECONOMIC ANALYSIS

Capital Costs

No full-scale activated carbon systems are known to have been installed in textile mills recently. Good capital cost information for the older installations is not available. Therefore, capital cost information was generated from cost curves in the literature (References 7 and 8). A 30-minute contact time is assumed, with off-site regeneration of spent carbon. Figure X-3 shows the capital cost (June 1983) for various components of the treatment system. The total system cost consists of the following items:

1. Equalization Tank
2. Filtration System
3. Carbon Contacting System
4. Treated Water Storage Tank
5. Equipment Installation (7% of items 1 to 4)
6. Piping, Electrical, Site Work (25% of items 1 to 4)
7. Contingency (10% of items 1 to 4)
8. Engineering (8% of items 1 to 4)

Operating Costs

Operating costs have been developed from data in the literature (References 7 and 8). A carbon exhaustion rate of 500 lb/million gallons is used in the replacement carbon costs. This cost will have to be adjusted to the actual carbon exhaustion rate in a given application of carbon adsorption technology. Figure X-4 shows the annual operating costs for activated carbon treatment.

Baseline Economics

To establish a starting point for determining the economics of this technology, a baseline or model case has been examined. The results of the analysis are summarized in Table X-2, and the assumptions used in the analysis are presented in Table X-3. The baseline economic analysis indicates that carbon adsorption technology has a very long payback period. This is due to high operating costs for carbon replacement and low value of recovered auxiliary chemicals.

Factors Affecting Economics

A sensitivity analysis for the effects of varying carbon exhaustion rates on the technology payback period is illustrated in Figure X-5. Higher carbon exhaustion rates result in increased operating costs, thereby increasing the payback period.

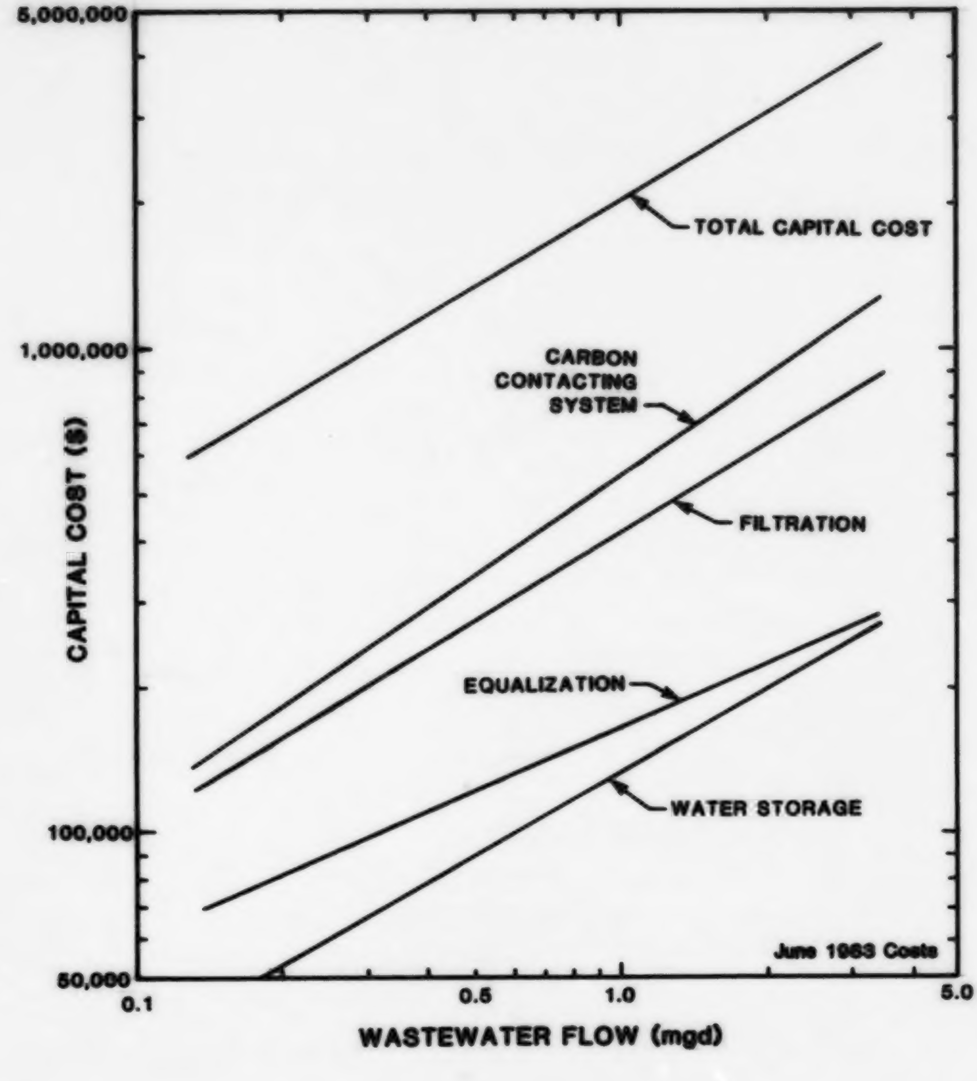

FIGURE X-3

ACTIVATED CARBON CAPITAL COSTS

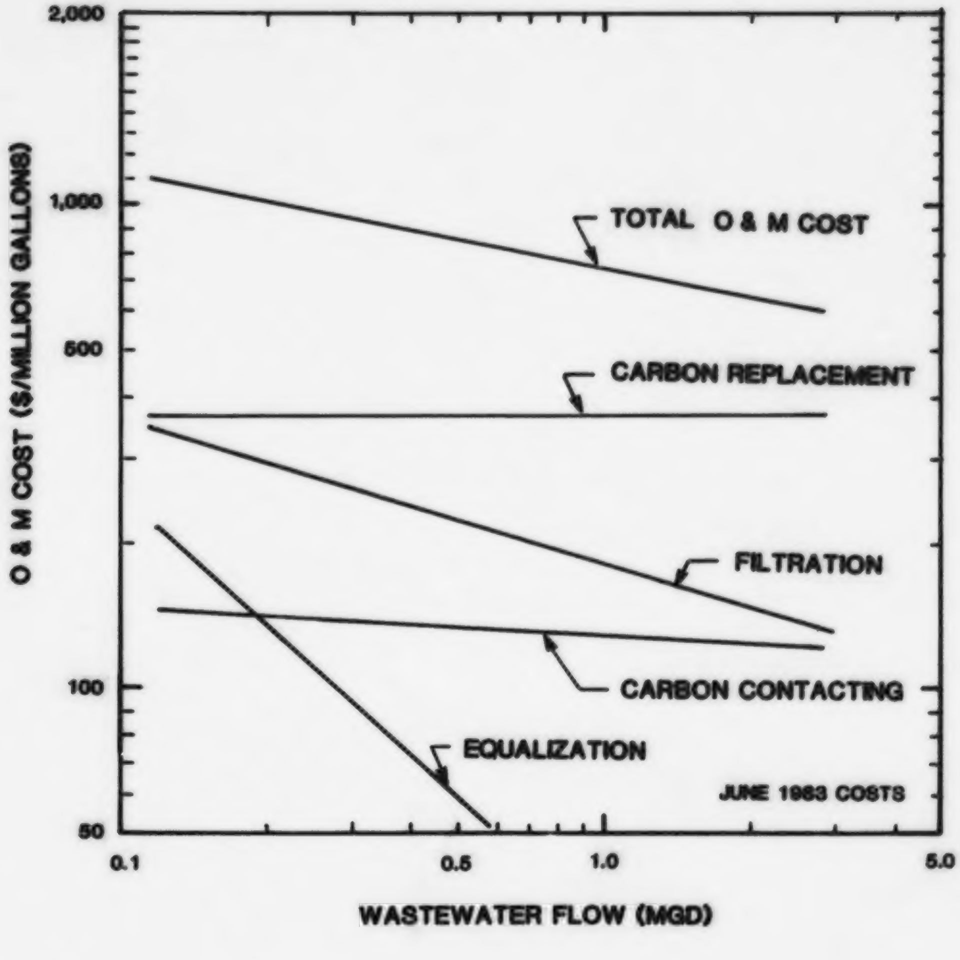

FIGURE X-4
ACTIVATED CARBON O & M COSTS

TABLE X-2

BASELINE ECONOMICS
DYE WASTEWATER DECOLORIZATION BY GRANULAR ACTIVATED CARBON ADSORPTION

Capital Costs, 1 mgd system (from curve in Figure 2)
(1982 dollars)

Equalization	$ 180,000
Filtration	430,000
Activated Carbon	580,000
Water Storage	130,000
Installation	100,000
Electrical, Site Work	340,000
Contingency	130,000
Engineering	110,000
Total	$2,000,000

Yearly O&M Costs

Labor	(1 manyear)	$ 20,700
Materials	(3% of capital)	60,000
Power		8,000
Carbon Replacement	(125,000 lb)	94,000
Total		$ 182,000

Yearly Savings

Water & Sewer	(0.8 mgd)	$ 200,000
Chemical	($0.005/lb product)	87,500
COD Surcharge	(500 lb COD/day)	18,750
Energy		--
Total		$ 306,000

Net Yearly Savings	$ 124,000
Payback Period	$2,000,000/124,000 = 16 years

TABLE X-3

BASIS FOR ECONOMIC ANALYSIS

Assumptions	
Production	70,000 lb/day, 250 day/year
Wastewater Flow	1,000,000 gpd
Recycle Flow	800,000 gpd
Benefits	
Water	$0.50/1,000 gal
Sewer	$0.50/1,000 gal
COD Surcharge	$0.15/lb
Auxiliary Chemical Value	$0.01/lb production
Auxiliary Chemical Recovery	50%
COD Removal	500 lb/day
Recycle Percentage	80%
Costs	
Labor	$12/hr, approximately 1 manyear required
Power	$0.05/kwhr
Overall O&M -	
Activated Carbon	$125/million gallons (including labor, power, materials)
Filtration	$180/million gallons
Equalization	$45/million gallons
Carbon Replacement	$0.75/lb, 500 lb/million gallons exhaustion = $375/million gallons
System Design	
Equalization	12 hour detention time
Filtration - Dual Media gravity (anthracite & sand)	
Rate	4 gpm/sq ft
Run Length	12 hours
Backwash	15 minutes at 15 gpm/sq ft
TDH	14 feet
Activated Carbon	down flow pressure
Contact Time	30 minutes
Hydraulic load	7 gpm/sq ft
Run Length	24 hours
Backwash	15 minutes at 18 gpm/sq ft
Head loss	37 feet
Water Storage	
Capacity	6 hours supply

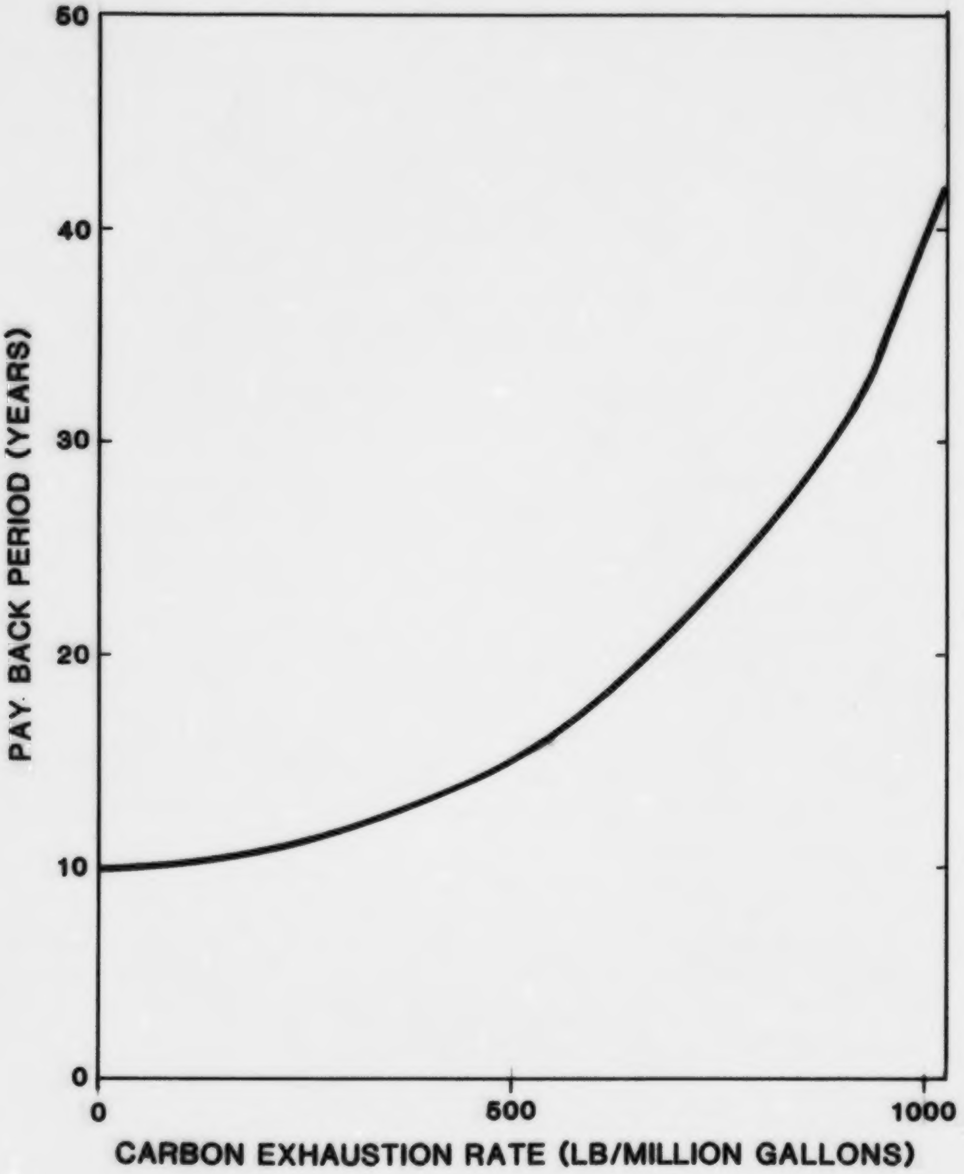

FIGURE X-5 EFFECT OF CARBON EXHAUSTION RATE

CURRENT APPLICATIONS

Several carbon adsorption systems installed for water recycle in the textile industry have been investigated and documented in the literature. The performance and characteristics of these systems are summarized in Table X-4.

The largest installation was at Hollytex Carpet in Southampton, Pennsylvania. This was a full-scale system used to treat wastewater from carpet rinsing and dyeing of pastel shades. Deep shade dyeing wastewater (about 20 percent of the total flow) was discharged directly to the city sewer.

The adsorption beds operated in a pulsed-bed, upflow mode, at a hydraulic loading rate of 4.7 gpm/ft^2. The contact time was about 42 minutes. The system experienced a carbon exhaustion rate of 550 lb/million gallons. Spent carbon was regenerated on-site in a 2,000 lb/day capacity, gas-fired multiple hearth furnace.

The treatment system consistently removed over 95 percent of the TOC and color from the wastewater. Treated wastewater was cooled and then stored in an elevated storage tank.

The 1969 capital cost for the system was $350,000, with operating costs reported to be $150/million gallons. Equivalent 1983 costs are $1,200,000 capital and $500/million gallons operating.

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2. Fram Corporation. Bio-Regenerated Activated Carbon Treatment of Textile Dye Wastewater, EPA Project 12090 DWM, January 1971.

3. Pardue, E. E., M. M. Stark, and B. M. Lalli. "Reclaiming Dye Wastewater for Reuse with Granular Activated Carbon," Book of Papers - National Technical Conference - AATCC, 1974, pp. 422-426.

TABLE X-4

APPLICATIONS OF CARBON ADSORPTION FOR TEXTILE WASTEWATER RECYCLE

Mill	Flow (mgd)	Wastewater Characteristics*			Carbon Contactor		Contact Time (min)	Exhaustion Rate (lb/1000 gal)
			Influent	Effluent	Type	Charge (lb)		
Hollytex Carpet	0.5	TOC	250	10	Pulsed	50,000	42 min	0.55
		Color	125	5				
Velvet Textile	0.06	TOC	175	--	Pulsed	40,000	51 min	--
		Color	--	none				
Westmill Carpet	0.035	COD	130	10	Pulsed	2,400	--	5.1
		Color	--	none				
Hanes** Hosiery	0.004	TOC	558	64	Fixed	--	--	--
		Color	--	none				

*TOC and COD are in mg/l. Color is in APHA units.
**Pilot-scale installation.

4. Phipps, William H. "Activated Carbon Reclaims Water for Carpet Mill," Water and Wastes Engineering, Vol. 7, No. 5 (May 1970), pp. C22-C23.

5. Roy, C. and B. Volesky. "Activated Carbon Adsorption Process for Purification of Textile Wastewater," Textile Chemist and Colorist, Vol. 10, No. 5 (May 1978), pp. 94-101.

6. Stark, M. M. and J. L. Rizzo. "Carbon Adsorption - Case Studies at Several Textile Plants," unpublished paper presented at Midwinter Conference on Textile Wastewater and Air Pollution Control, January 23-25, 1974.

7. U.S. EPA. Development Document for Effluent Limitations, Guidelines, and Standards for the Textile Mills Point Source Category, EPA 440/1-82/022, NTIS No. PB83116871, September 1982.

8. U.S. EPA. Innovative and Alternative Technology Assessment Manual, EPA-430/9-78-009, NTIS No. PB81103277, February 1980.

SECTION XI

DYE RECOVERY BY ULTRAFILTRATION/HYPERFILTRATION

INTRODUCTION

Ultrafiltration and hyperfiltration (UF and HF) are pressure-driven membrane separation processes that can be used to treat textile dye wastewater for reuse of hot permeate and possible recovery of dyes and auxiliary chemicals in the concentrate. A schematic of the process is presented in Figure XI-1. UF is suitable for separation of dyes in colloidal form or with high molecular weights (>500) such as indigo and some other vat or sulfur dyes, while HF is suitable for separation of most dyestuffs and auxiliary chemicals. The objectives of the technology are dyestuff and auxiliary chemical recovery, water and energy savings, and sewer use fee savings. Membrane separation technologies are intended for use on washwater from continuous dyeing where separation and concentration of the chemicals are necessary prior to reuse.

These membrane separation technologies are capital intensive, and payback periods may range from one to five or more years, depending primarily on the value of recovered dyes and chemicals. Specific factors that affect the technical and economic feasibility of these technologies are addressed below.

ENVIRONMENTAL BENEFITS

Dye wastewater generally contains substantial amounts of BOD, COD, and color, with amounts depending on the dye formulation. The pollutants are a result of the dye formulation itself so that dye and auxiliary chemical recovery should effect a BOD, COD, and color reduction proportional to the pollutant load contributed by the dyeing process. The ultimate effect on a mill's final discharge depends on the amount of dyeing conducted relative to other mill processes.

Conclusive investigations of dye recovery systems for pollutant discharge reductions have not been documented, although up to 95 percent water recovery and recycle has been experienced. Pollutant

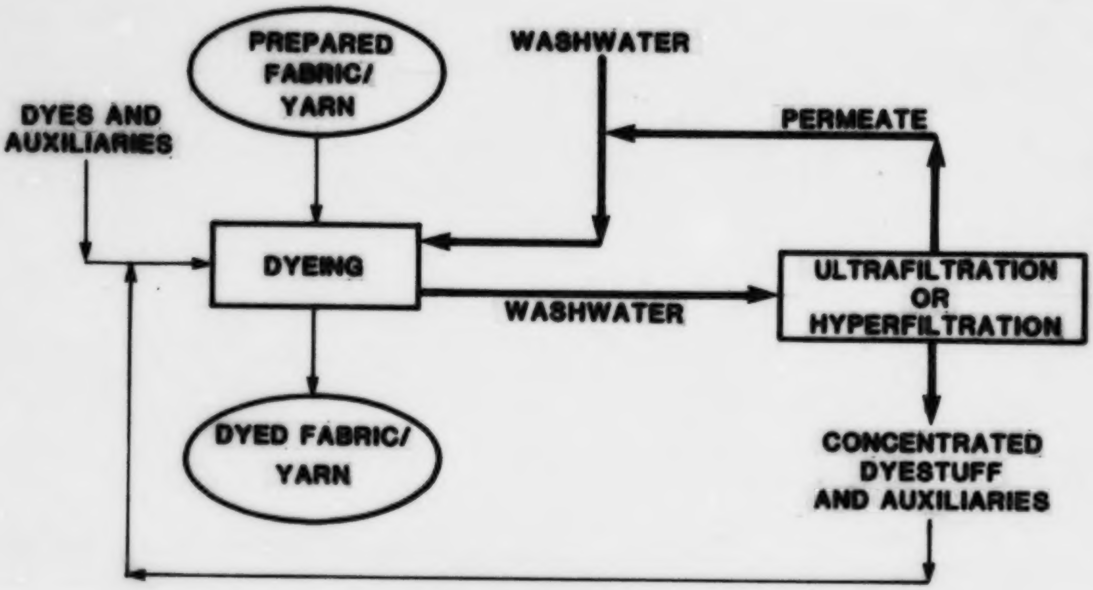
PREPARED FABRIC/ YARN
WASHWATER
DYES AND AUXILIARIES
PERMEATE
DYEING
ULTRAFILTRATION OR HYPERFILTRATION
WASHWATER
DYED FABRIC/ YARN
CONCENTRATED DYESTUFF AND AUXILIARIES

FIGURE XI-1
MEMBRANE SEPARATION PROCESS SCHEMATIC
FOR DYESTUFF RECOVERY

discharge reductions of up to 90 percent of original process discharge are likely, provided that auxiliary chemical and dyestuff reuse are practiced.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description

Membrane separation processes rely on semi-permeable membranes to achieve separation of dyes and auxiliary chemicals from the water used in the dyeing operation. The membrane is permeable to the solvent (water) but impermeable to the solute (dyes, chemicals). The pressure difference across the membrane is the driving force causing water to permeate the membrane. The water flux through the membrane is generally described as:

$$F = \frac{K \Delta P}{V}$$

where F is the flux, ΔP is the pressure difference, V is the water viscosity, and k is a membrane resistance coefficient. In certain cases, the osmotic pressure must be subtraced from the actual pressure difference to obtain the net ΔP for water flux.

The membrane resistance coefficient is temperature-dependent, increasing with higher temperatures. Thus, higher flux rates are obtained with hot dyeing wastewater, as compared to cooler dyeing wastewater. Other factors such as flow turbulence, solute layer buildup on the membrane surface, and feed wastewater concentration can affect the actual flux rate achieved.

Ultrafiltration is a relatively low pressure process used for the recovery of high molecular weight substances. Hyperfiltration uses a higher pressure and different membrane to recover smaller molecules. A comparison is shown below:

	Ultrafiltration	Hyperfiltration
Driving Force	5 to 100 psi	100 to 1000 psi
Species Separated	colloids high M.W. organics	ions, inorganics organics, colloids
Typical Water Flux	20 to 50 gpd/ft^2	5 to 40 gpd/ft^2

Thus, ultrafiltration is generally used in applications such as indigo recovery (large, colloidal particles), whereas hyperfiltration is used for soluble dyestuff recovery.

Ultrafiltration membranes are available in tubular, spiral-wound, hollow fiber, and plate-and-frame configurations, whereas hyperfiltration membranes are available basically in tubular and spiral wound configurations.

Tubular. Tubular membranes consist of parallel bundles of porous tubes, generally less than 1 inch in diameter. The inside tube walls are coated with the membrane material. Pressurized feed is introduced inside the tubes. Water permeates to the outside of the tube walls and is collected, while the concentrated dyestuff stream is formed inside the tubes.

Spiral Wound. Spiral wound membranes consist of a sandwich of two membrane sheets with a permeate conducting layer between them. This assembly is rolled around a perforated permeate collection pipe, forming a cylindrical module.

Hollow Fiber. The hollow fiber configuration is similar in concept to the tubular configuration. The hollow fibers are constructed of noncellulosic, synthetic polymers and are anisotropic, with the membrane skin formed on the inner surface. Individual fiber bundles are assembled inside tubes to produce cartridges with high membrane surface area to volume ratios. The hollow fiber configuration may be cleaned by a choice of detergent cleaning or backflushing.

Plate-and-Frame. The plate-and-frame configuration resembles a conventional plate and frame filter. Alternating layers consisting of membrane material, porous support sheet, membrane material, and membrane spacer are stacked into a vessel. Feed is introduced under pressure into the membrane spacers. Water (permeate) passes through the membranes and is collected from the porous support sheets between alternating membranes.

Membrane Material. Early ultrafiltration and hyperfiltration designs relied on cellulose acetate membranes. However, these membranes cannot withstand the extremes in temperature and pH encountered in textile dyeing wastewater. The more recent use of many different polymers for membrane formation has provided membranes that can be applied to textile dyeing wastes. At present, many ultrafiltration systems for dyestuff recovery are based on polysulfone membranes, due to this polymer's strength, durability, solvent resistance, and ability to operate at high temperatures (to 200°F) and over a wide pH range (0.5 to 13). For hyperfiltration applications, dynamically formed hydrous zirconium (IV) oxide-polyacrylate (ZOPA) membranes have shown much promise. A hydrous Zr(IV) oxide membrane is first formed on the porous support by circulating a solution containing a colloidal suspension of the oxide. This membrane is then exposed to a low pH polyacrylic acid solution which deposits a thin polyacrylate membrane over the oxide membrane. This membrane is also very resistant to high temperatures and pH extremes, and has the advantage of yielding a higher water flux than conventional cellulose acetate or polymer based hyperfiltration membranes.

Design Criteria

Control Modes. The discussion of control modes in Section VI is applicable here. Small systems will use the simple batch mode or a continuous feed and bleed mode. Large systems will generally use multi-staged continuous systems with three or four stages.

System Design. The general discussion of design considerations found in Section VI applies again here. Flux data generally must be developed on a pilot scale for a particular waste stream to optimize the design. Typical flux rates for UF range from 5 to 15 gpd/ft^2 for plate and frame, and 30 to 35 gpd/ft^2 for hollow fiber. For HF, a flux rate of 5 to 10 gpd/ft^2 for spiral-wound and 30 to 40 gpd/ft^2 for tubular with zirconium oxide polyacrylate (ZOPA) membranes have been typical. HF system pressures are typically around 1,000 psig. Typical process flow diagrams are presented below in the discussion of current applications.

Performance and Operating Characteristics. The parameters used to evaluate size recovery that were discssed in Section VI are also applicable here, except that rejections of color and TDS (or conductivity) rather than dye or size are used as measures of performance. Values for color rejection generally exceed 98 percent in successful applications, with 70 to 85 percent conductivity rejections. In the detailed research conducted on HF of dye wastewater at LaFrance Industries, LaFrance, South Carolina, numerous other tests were performed to identify potential problems. The tests on the permeate included degree of fabric staining by permeate, measurement of COD, TS, VS, and pH as an indication of pass-through of auxiliary chemicals, and foam tests to estimate the amount of surfactant passing through. Tests on the concentrate helped to determine dye and chemical savings by reconstitution of dye formulas and test dyeings. The results are discussed below briefly in the material on current applications, and in more detail in the published research reports on the LaFrance project.

FACTORS LIMITING TECHNICAL FEASIBILITY

It is evident that the technical aspects of dye recovery and reuse are more complicated than those of size recovery due to the extensive variety of dye formulations. Research efforts to date have begun to establish a means to identify and solve the problems at a particular mill. Several factors that affect technical feasibility are listed and discussed below.

- Composition of recovered dye
- Tolerance of recovery system
- Countercurrent flow
- Buildup of impurities
- Dye type

Composition of Recovered Dye

The composition of the recovered dye should be as uniform as possible to facilitate dye reuse. For example, in indigo dyeing, dyestuff recovery and reuse is readily practiced since only one dyestuff is contained in the recovered dye concentrate stream. At most finishing mills, however, a mixture of dyestuffs is used and the fabric shades vary from lot to lot. In these cases, the scheduling of repeat dyeing and the sequence of shades dyed should be scheduled such that color changes are made gradually. A dye analysis/reconstitution procedure, such as that used in batch dyebath reconstitution, may be required to facilitate dye reuse. Work on dye reuse is currently under way at LaFrance Industries.

Tolerance of Recovery System

Membranes must be evaluated and chosen carefully to tolerate the full range of conditions expected in the dye wastewater. Fibers, pH, solvents, and temperature are among the parameters that may adversely affect the recovery system and membranes. Pretreatment measures, such as filtration or cooling, may be needed prior to the membrane separation step.

Countercurrent Flow

The use of countercurrent flow in the rinsing stages is necessary in order to provide the lower volume/higher concentration wastewater required for dyestuff/auxiliary chemical recovery at a reasonable cost. The technical feasibility of countercurrent flow must be evaluated to assure that fabrics are adequately rinsed in such a system.

Buildup of Impurities

Impurities such as salts and low molecular weight dyes or solvents may build up quickly in either the permeate or concentrate streams and render them inappropriate for reuse. For example, in indigo recovery by UF, calcium salts and sulfur dyes (if used) can accumulate in the permeate so that it cannot be reused. In an HF system, impurities may build up in the concentrate and make it difficult to reuse. In cases where such buildup of impurities may occur, the blowdown of a portion of the permeate or concentrate should be investigated.

Dyestuff Type

Limited research indicates that some dyes and dye formulas can be separated more readily or completely than others. Direct and disperse dyes generally show the most complete separation by hyperfiltration. Acid and basic dyes are also separated by HF. Sulfur dyes (mixed with indigo dyes) will pass through an UF system. Certain formulas (for example, some basic/direct and acid/direct dyeing formulas) contain a low molecular weight solvent that passes through the HF membrane and causes a high COD and VS in the permeate.

ECONOMIC ANALYSIS

Capital Costs

Figure XI-2 presents a capital cost curve for membrane separation treatment of washwater from continuous dyeing processes. The costs are based on vendor quotations for standard size treatment modules and on literature information for the LaFrance Industries project. Added to the basic equipment costs are the following items:

UF/HF equipment and pumps	Base
Equipment installation	7%
Tankage, piping, filters	20%
Electrical	5%
Engineering	8%
Contingency	10%
	150% of base cost

The curve in Figure XI-2 represents this total capital cost in June 1983 dollars. It should be noted that these costs are valid for water flux rates of about 30 to 40 gpd/ft^2 and are thus applicable for most ultrafiltration membranes and for ZOPA hyperfiltration membranes. Standard hyperfiltration membranes (e.g., acetate) have much lower flux rates, and the capital cost for such systems can be higher or lower depending on membrane type and required area.

Operating Costs

Figure XI-2 presents a cost curve of operation and maintenance costs for membrane separation treatment of dye wastewater. These costs are based on vendor estimates and on limited full-scale operating data for the LaFrance Industries project. The yearly cost includes operating labor, maintenance labor, maintenance parts, replacement membranes, and pumping costs.

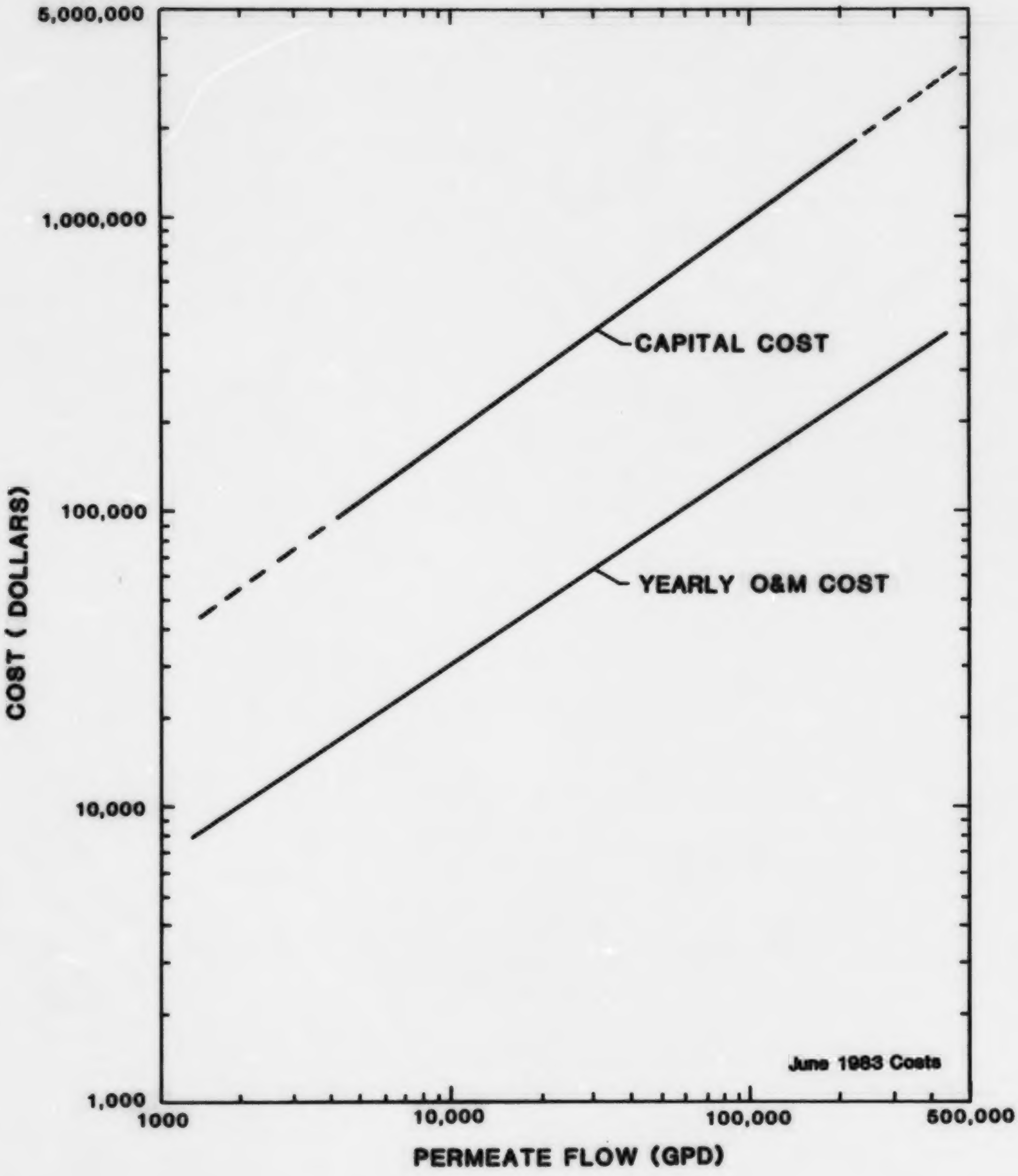

FIGURE XII-2 DYESTUFF RECOVERY
MEMBRANE SEPARATION PROCESS COSTS

Baseline Economics

The economic feasibility of dyestuff recovery and water recycle by membrane separation treatment depends to a large degree on several variables, including the value and reusability of the recovered dyestuff, the water flux rate of the membrane, and several others. A baseline or model case is examined below to illustrate the economics of this recycle technology. The effects of various factors affecting the economics are then considered.

Table XI-1 shows the economic analysis for a 50,000-gpd membrane separation process to treat and recover dyestuffs and auxiliary chemicals from the washwater of a continuous dye range. The treated washwater is also assumed to be recycled. Further assumptions and unit costs used in the model case are presented in Table XI-2.

For this model case, the payback period is estimated to be three years. Payback periods for this technology typically range from less than one year to about five years.

Factors Affecting Economics

The primary factor affecting the economic feasibility of this recycle technology is the value of the concentrate stream. This value can range from zero, for systems where the concentrate is not reusable, to $2 per gallon for valuable dyestuffs (e.g., indigo). Figure XI-3 shows the effect of concentrate stream value on the economics (payback period) of the technology.

Other factors will have some effect on the payback period. As mentioned above, the use of conventional hyperfiltration membranes as opposed to ZOPA membranes can affect the system capital cost. More importantly, such membranes can often require cooling and extensive prefiltration, thereby increasing operating costs and eliminating energy savings from hot water recycle.

CURRENT APPLICATIONS

Two known full-scale installations for dye recovery are listed and described below.

- Ultrafiltration (plate and frame) for indigo recovery

TABLE XI-1

BASELINE ECONOMICS
DYESTUFF RECOVERY

Capital Cost @ 50,000 gpd		$650,000
Yearly O&M Cost		$100,000
Yearly Savings		
	Dye & Chemical	$ 262,000
	Water & Sewer (36,000 gpd)	$ 11,000
	Energy (30 mm BTU/day)	$ 36,000
	BOD Surcharge (140 lb/day)	$ 6,000
	Subtotal	$ 315,000
Net Yearly Savings		$ 215,000
Payback Period		$\frac{\$\ 650{,}000}{215{,}000} = 3$ yrs

TABLE XI-2

BASIS FOR ECONOMIC ANALYSIS DYESTUFF RECOVERY

ASSUMPTIONS

Dyeing Production: 50,000 lb fabric/day
300 days/yr.
One dye type assumed separable by HF

Water Use in rinses: 1 gal/lb
Wastewater: 50,000 gal/day (35 gpm)

Value of concentrate: $0.25/gallon
Percentage of reusable concentrate: 70% (30% blowdown), or 3,500 gpd

Permeate production: 90% of flow
Concentrate production: 10% of flow

Permeate blowdown: 20% of permeate
Concentrate blowdown: 30% of concentrate

Water Savings: $0.50/1,000 gallons } for 36,000 gpd
Sewer Use Savings: $0.50/1,000 gallons } for 36,000 gpd

Energy Savings: $4/million Btu
Process water temp = 75°C
Incoming water = 20°C

BOD in dye wastewater: 500 mg/l, 200 lb/day
96% to concentrate; 4% to permeate

BOD Savings: $0.15/lb for 140 lb/day

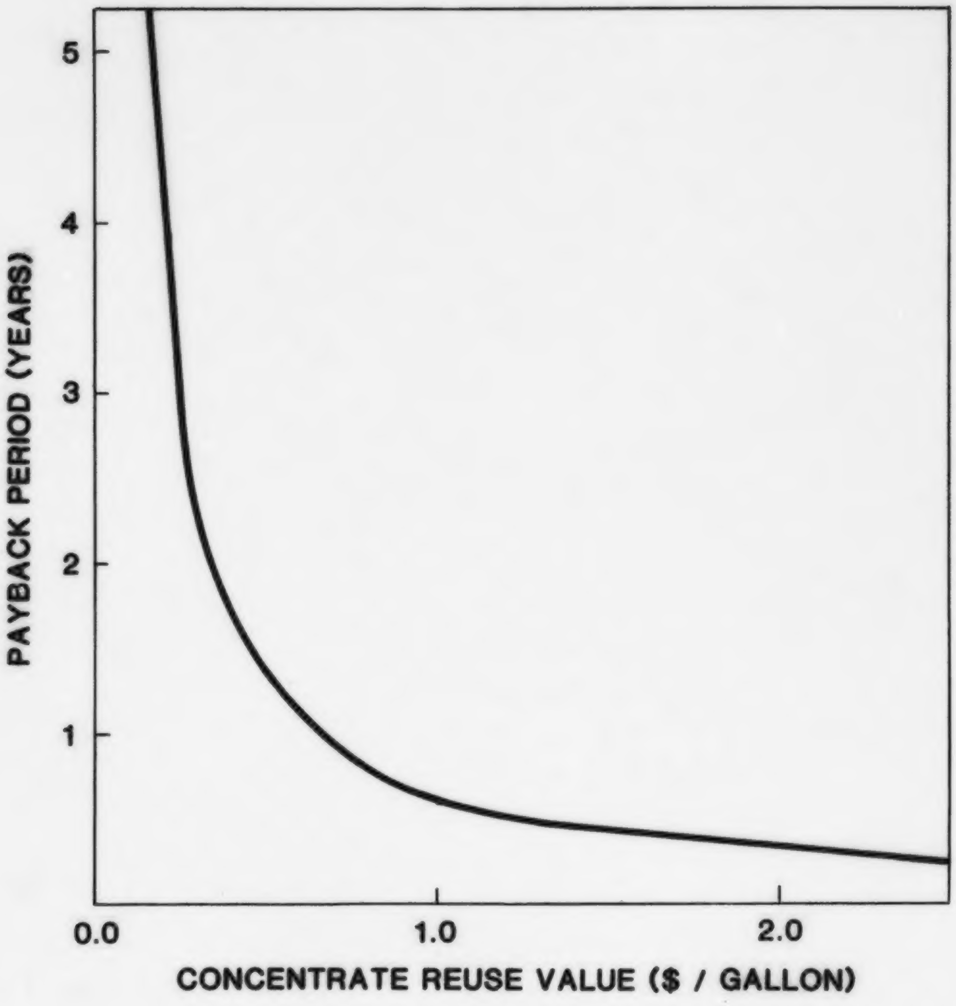

FIGURE XI-3 EFFECT OF DYE/CHEMICAL SAVINGS

- Riegel Textiles, LaFrance Industries - Hyperfiltration for dye and chemical recovery.

Indigo Recovery System (Plate and Frame)

This full-scale system relies on the plate and frame UF system for indigo recovery marketed by Dorr-Oliver, Inc. Operation and performance data have not yet been published, but a description of the typical Dorr-Oliver system is applicable. A typical flow diagram for the system is provided in Figure XI-4.

The mechanical arrangement and description of operation are provided below.

Sump. Counter-current rinse water overflow is discharged into a sump which is also used to periodically drain the rinse boxes.

Screen. A 325 mesh vibrating screen is the primary lint removal device and has proved to be dependable. A 200 mesh basket strainer is in the line subsequent to the Sweco and is usually cleaned once per shift.

Storage Tank. A storage tank for screened rinse water is recommended. It should have about eight hours of rinse flow capacity (15,000 gallons for a typical range).

Feed Tank (250 gallons, typical). Isolates ultrafilter from static head of storage tank. Alternates with RIP tank during daily membrane regeneration regime.

RIP Tank (250 gallons, typical). Used for membrane regeneration in conjunction with feed tank.

Ultrafilter. A three- or four-stage system incorporating diafiltration in part of the final stage to insure non-indigo solids do not rise above a preestablished level.

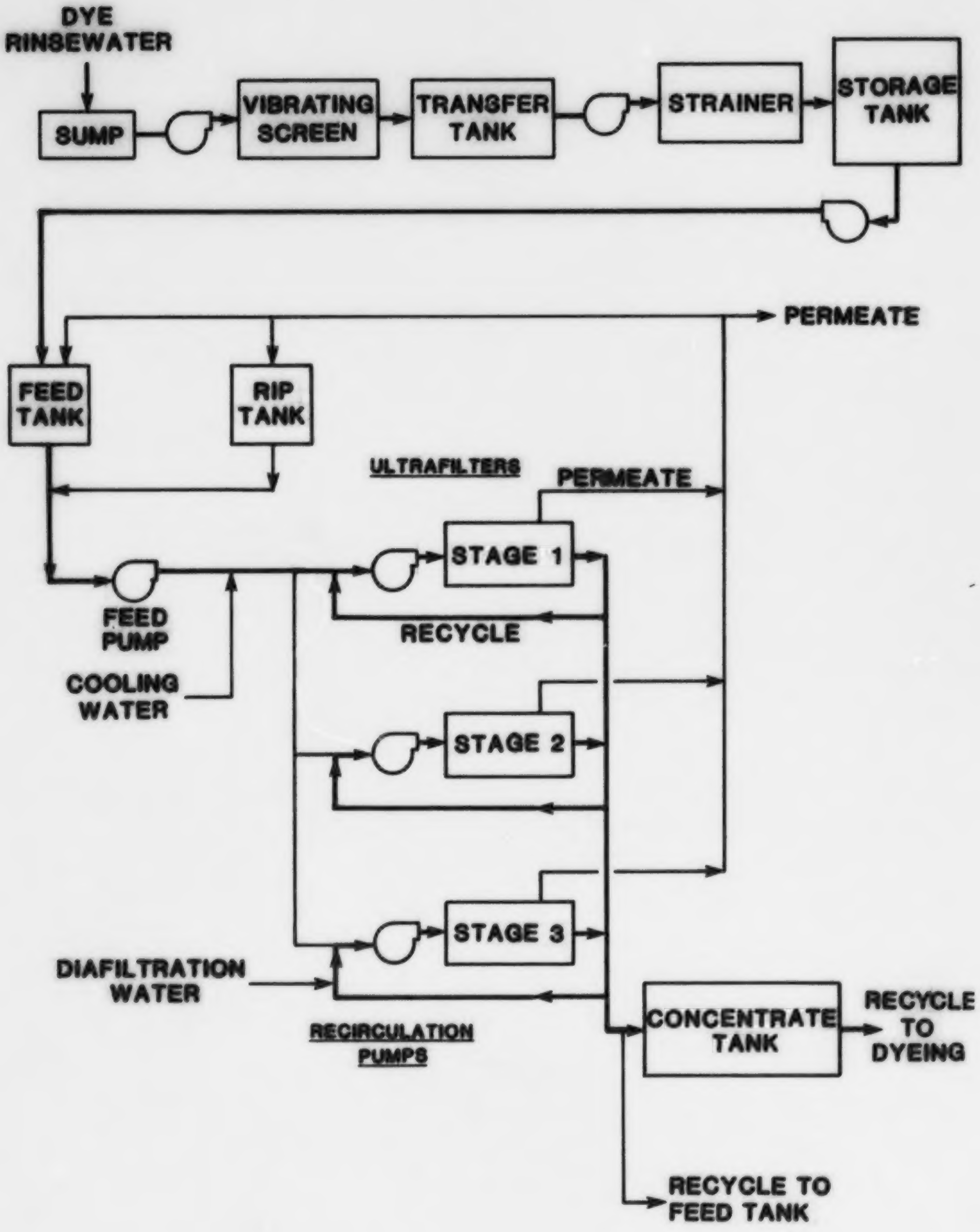
DYE RINSEWATER
SUMP
VIBRATING SCREEN
TRANGFER TANK
STRAINER
STORAGE TANK
PERMEATE
FEED TANK
RIP TANK
ULTRAFILTERS
PERMEATE
STAGE 1
FEED PUMP
RECYCLE
COOLING WATER
STAGE 2
STAGE 3
DIAFILTRATION WATER
RECIRCULATION PUMPS
CONCENTRATE TANK
RECYCLE TO DYEING
RECYCLE TO FEED TANK

FIGURE XI-4 FLOW DIAGRAM OF INDIGO RECOVERY SYSTEM

Concentrate Collection Tank (6,000 gallons, typical). Holds about four days supply of concentrate at 2 to 2-1/2 percent indigo solids.

Operation -- Normal Processing. Indigo rinse water is pumped from the sump to the vibrating screen where most of the lint is removed. The screened rinse water is discharged into a small transfer tank (about 100 gallons) from where it is pumped through a 200 mesh basked strainer into the feed collection tank. The basket strainer is normally cleared once per shift. The rinse water is pumped into the ultrafilter feed tank through a level control valve. The feed pump takes suction from the feed tank and delivers the rinse water to the first stage of the ultrafilter. The feed flow is measured with a magnetic flow meter.

After progressing through the three stages of ultrafiltration, the concentrate goes to the concentrate control valve operated by an intermittent automatic ratio controller that has received feed and concentrate flow rates from the flow meters. Concentration ratios required are normally in the range of 30:1 to 50:1, which would indicate a concentrate flow rate of between 0.5 and 0.8 gpm assuming a feed rate of 25 gpm. This flow is too small to control accurately on a continuous basis, so an open/shut valve is supplied. Assuming that the concentration ratio is 50:1, the ratio controller will permit 50 gallons of feed to enter the system, then open the concentrate flow control valve to let one gallon out before closing. Virtually any ratio can be selected at the control panel, thereby giving the ultrafilter the flexibility of accommodating wide variations in rinse water composition and still produce a consistent concentrate.

A process called diafiltration is employed on the final stage of the ultrafilter. A small amount of water, less than one gpm, is injected into the final recirculation loop to reduce the level of non-indigo solids which are partially retained by the membrane. The objective is to limit the buildup of calcium or other salts to 2 percent.

Concentrate is stored in a collection tank until combined with virgin dye for reuse.

Automatic Recycle. In practical terms, it is impossible to match the through-put rate of the ultrafilter with the rinse overflow rate all of the time. To prevent overflow of the feed tank, the ultrafilter capacity must exceed the highest expected rinse water rate. Thus, the ultrafilter will be processing at a higher rate than the rinse water is being produced, and occasionally the feed collection tank will run dry and the ultrafilter shut down.

This situation is avoided by automatic recycle. When the rinse water level in the feed collection tank nears bottom, the feed transfer pump automatically shuts down and no more feed is delivered to the feed tank. The concentrate and permeate recycle valves are then automatically positioned so that both of these streams are returned to the feed tank. A small amount of permeate, however, continues to go to drain and is made up by an equal volume of water injected into the three stages. The water injection is necessary to cool the system, since all the energy of the large recirculation pumps is converted into heat. There is also the ancillary benefit of additional diafiltration as a result of the cooling water injection, which is controlled by a float valve in the feed tank.

The automatic recycle feature permits the ultrafilter to operate normally at all times and avoids the problems associated with repeated start-ups and shutdowns.

Membrane Regeneration. During normal operation, the flux rate gradually declines with time due to the buildup of a flux-limiting film on the membrane surface. The systems normally operate for 22 continuous hours and then go into a regeneration regimen which consumes less than two hours. The flux at the end of the 22nd hour is about one third of the initial flux, with most of the decline taking place during the first ten hours of operation.

There is no evidence that the flux fouling film affects the selectivity of the membrane.

The regeneration procedure consists of two water rinses, a detergent rinse, and a final water rinse. The RIP (regeneration in place) tank is used in conjunction with the feed tank during the regeneration process, permitting operation on one tank while the other is filled.

When the process cycle is terminated, the concentrate in the final stage is at full strength. Rather than return it to the sump, as is done in the prior stages, the feed pump is employed to evacuate the last stage and send the recovered concentrate to storage.

Riegel Textiles, LaFrance Industries, LaFrance, South Carolina

A full-scale demonstration of hyperfiltration for dye recovery is in progress at the mill, with research funding provided by U.S. EPA, Department of Energy, and Department of the Interior. Numerous publications are available that describe the entire research project since its inception in 1972 and are listed in the references. A summary of the full-scale system is provided below.

The LaFrance dyehouse processes a wide range of fabrics, including cotton, acrylic, nylon, rayon, polyester, and numerous blends. The dye formulations are varied to accommodate the wide range of fabrics and include direct, disperse, acid, basic, premetallized, and reactive dyes. A typical dyebath on the continuous range includes dyes, thickener, and some dye solvents. The recovery system operates in conjunction with dye runs so that each type is treated separately for reuse.

A recovery system schematic is provided in Figure XI-6. The system relies on a ZOPA hyperfiltration HF module as marketed by Mott-Brandon Corporation.

The recovery system is designed to collect all water from the dye range and supplies the fluid to the hyperfiltration (HF) unit. The permeate from the HF unit is returned to the range as hot wash water and the concentrate is collected for reuse or disposal. Operation of the range is independent of operation of the recovery system. Automatic

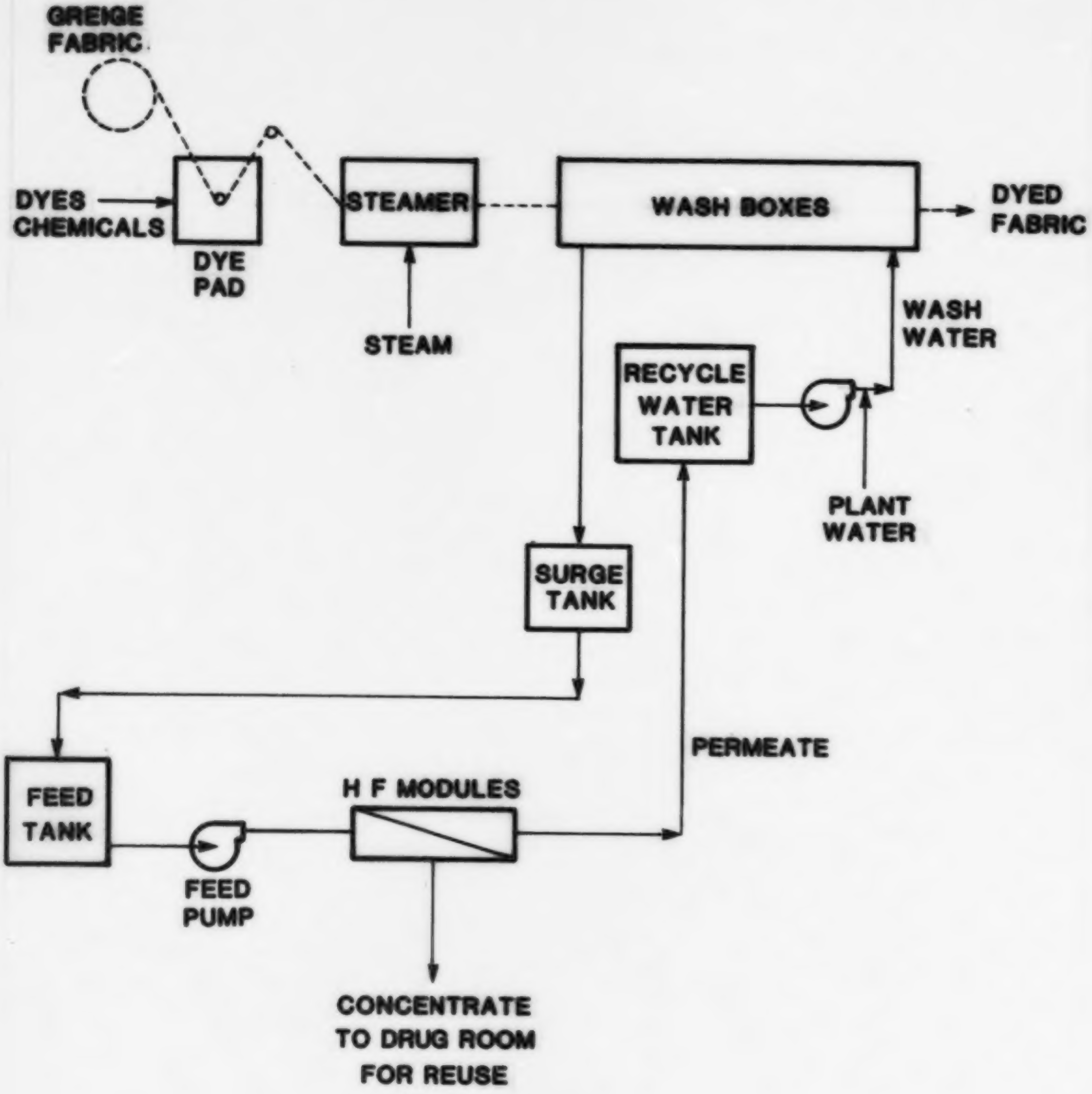
GREIGE FABRIC
DYES CHEMICALS
DYE PAD
STEAMER
STEAM
WASH BOXES
DYED FABRIC
WASH WATER
RECYCLE WATER TANK
PLANT WATER
SURGE TANK
PERMEATE
FEED TANK
FEED PUMP
H F MODULES
CONCENTRATE TO DRUG ROOM FOR REUSE

FIGURE XI-5 LAFRANCE HYPERFILTRATION SYSTEM

controls allow for continuous operation. Additional instrumentation is installed to record operation parameters of economic importance.

Design Flows. The design wash water flow rate is 174 liters per minute (46 gpm). The assumed fabric speed is 18 meters per minute.

The average lot size is 10 pieces of fabric (one piece = 50 meters). Each lot is separated by approximately 20 minutes from the next lot. During this 20 minutes the wash water flow is continued. (In the original design it was assumed that the washers would be drained.) The total volume drained during this average cycle resulted in an average flow rate of 174 liters per minute.

Surge Tank. The tanks are sized to accommodate surges representing maximum deviations in water use and also provide for about two hours of HF unit down time. The maximum deviation envisioned is two consecutive shifts with consecutive 80 piece lots. The two large tanks were sized at 23 m^3.

Concentrate Tank. The concentrate tank is sized to accept the concentrate from one 80 piece dye run, 3000 liters (800 gallons). The HF unit is designed to concentrate to 75 percent of the dye liquor volume to allow for the addition of make-up chemicals for reuse.

Operation. The range is modified for counter-flow washing with the overflow to drain from the jet washer. The drains and overflows are collected in a sump and pumped to the wastewater tank. The drain piping and sump pump are designed to accept short-term surges up to 1,514 liters per minute (400 gpm) during system draining.

Of the total flow supplied to the range, a substantial fraction is used to remove lint by reverse spray of three rotating screen filters. Approximately 23 liters per minute (6 gpm) are used at each filter with about one third escaping from the system with the lint cake. Rather than use permeate for this backwash function, water is now diverted from the washer circulation within each washer. Lint baskets of screen wire are provided to catch the lint cake. The baskets are fitted with a fluid collection pan so that the fluid draining from the lint is routed to the sump.

Remaining dye pad formulation after a dye run is transferred to the concentrate tank.

Variations in flow rates are accommodated by control of the flow to range, the HF concentrate flow control, and automatic use of plant water when required. For continuous HF system operation, the design concentrate flow is 11.4 liters per minute (3 gpm). The flow rate to the dye applicator from the drug room depends on the range speed. The design assumes 1 liter of dye solution is added for each meter of fabric. The average flow rate of dye solution, however, depends on lot size because the 140 meters of leader on each end of each lot does not require dye solution. Also there is no dye solution flow for 20 minutes between each lot. The average drug room flow is thus quite small for small lot sizes and asymptotically approaches 1 liter per meter of fabric. For an average lot size of 20 pieces, about 4 liters/minute of water are required for chemical additions in dye reuse, in addition to concentrate recycle.

Permeate Reuse. The system has fairly consistently produced a permeate suitable for reuse at the dye range washers, with color rejections generally exceeding 98 percent and conductivity rejections generally from 70 to 85 percent. Flux rate has averaged about 30 GFD.

Limited investigations show that dye type and fabric type must be considered for permeate reuse, as certain low molecular weight solvents pass through the membrane and cause a high COD and VS in the permeate. Cotton fabrics have stained more readily then acrylics in reuse of permeate from direct dye separation.

Concentrate Reuse. Concentrate reuse trials are in progress and extensive data are being gathered. Published results to date indicate that the weighted dye reduction savings are about 19 percent, consisting of 23 percent direct, 10 percent basic/direct and 0 percent disperse. Production levels associated with these reductions are 67 percent direct, 24 percent basic/direct, and 1 percent disperse. An overall reduction of 50 to 75 percent of auxiliaries has been achieved.

Economics. The estimated capital costs, yearly operating costs, and yearly savings (in 1981 dollars) are presented in Table XI-3. These costs are based on the actual capital costs incurred in the demonstration project and on preliminary operating results. The estimated yearly savings are projected to be $275,000 when concentrate reuse is more fully implemented.

TABLE XI-3
HYPERFILTRATION ECONOMICS

Capital Costs (1981)	
Hyperfiltration Unit	$300,000
Other Equipment Items	36,000
Piping	38,000
Electrical/Instrumentation	35,000
Labor, Taxes, Other Indirect Costs	60,000
Engineering	15,000
	$484,000
Yearly Operating Costs (1981)	
Labor	$ 22,700
Materials/Supplies	5,100
Membrane Replacement	20,000
Power	6,000
Concentrate Disposal	15,000
Taxes/Insurance	5,000
	$ 73,800
Yearly Savings (1981)	
Dyes/Chemicals	$ 25,000
Energy	45,400
Water/Wastewater	6,900
Plant Overhead	13,000
	$ 90,300

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SECTION XII

COAGULATION/FLOTATION OF PRINT WASTEWATER

INTRODUCTION

Coagulation and dissolved air flotation (DAF) are used to treat printing wastewater and enable the recycle of clarified effluent. Aluminum or iron salts serve as the principal coagulants, often assisted by polymers. The clarified effluent is reused for noncontact cleaning of printing machinery, and the float solids are dewatered and incinerated or disposed in a landfill. A process schematic is provided in Figure XII-1. In some cases where solvents are used, they are stripped from the float solids by steam and recovered. Savings are realized in process water costs and sewer use charges, and chemical costs if solvents are recovered. Payback periods of about seven to ten years are expected.

ENVIRONMENTAL BENEFITS

Coagulation/flotation systems are effective primarily for solids/liquid separation. In the case of treatment of printing wastewater, this results in significant removal of BOD, COD, TSS, phenolics, turbidity, and color. Metals such as chromium, copper, and zinc (if present) are removed from the wastewater and discharged in the DAF sludge. Increases in soluble aluminum, iron, sulfate, and chloride concentrations may result from the addition of aluminum and iron salts as coagulants.

Wastewater data collected at Mill W-3 during Phase II of this project indicated that the coagulation/flotation system removes about 70 percent of the organics (BOD or COD), solids, and phenolics present in the printing wastewater. Removals of metals were as follows: chromium 63 percent, copper 74 percent, and zinc 56 percent.

PROCESS DESCRIPTION AND DESIGN CRITERIA

Process Description - Coagulation

Generally, printing wastewaters are predominantly particulate and colloidal in character, containing substances such as printing

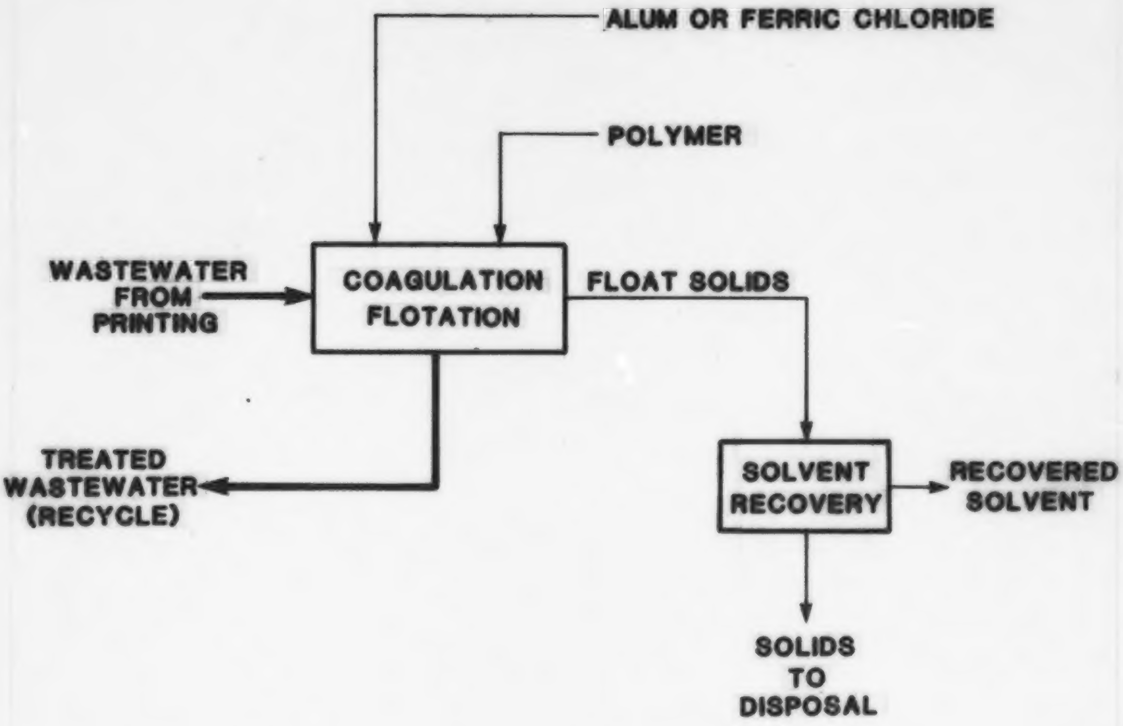

ALUM OR FERRIC CHLORIDE
POLYMER
WASTEWATER FROM PRINTING
COAGULATION FLOTATION
FLOAT SOLIDS
TREATED WASTEWATER (RECYCLE)
SOLVENT RECOVERY
RECOVERED SOLVENT
SOLIDS TO DISPOSAL

FIGURE XII-1 SCHEMATIC OF PRINTING WASTEWATER RECYCLE SYSTEM

dyestuffs and pigments, adhesives, emulsified mineral spirits, acrylic latex emulsion, and solvents. Therefore, it is appropriate to consider briefly the aspects of coagulation theory that may affect the design and operation of a coagulation system.

The two most important steps in coagulation are particle destabilization and particle transport.

Particle Destabilization. Particle destabilization refers to concepts in colloid chemistry that explain how particles may attach to other particles and hence facilitate their removal from suspension by either flotation or sedimentation. Destabilization is achieved by the following mechanisms:

1. Neutralization of a diffuse charge layer on the particles;
2. Adsorption and charge neutralization;
3. Enmeshment in a precipitate (or float);
4. Adsorption by interparticle bridging.

Experimental research (Ref. 2) has shown that the most important mechanisms in destabilization of the colloids in printing wastewater are enmeshment and interparticle bridging.

Metallic salts of iron and aluminum have been the most successful in the coagulation of printing wastewaters. They form gelatinous hydroxide precipitates in water that have the ability to enmesh the colloidal wastewater particles and to polymerize some species for interparticle bridging. Addition of polymer has also been successfully practiced at Mill W-3 to aid the destabilization process by further interparticle bridging.

The use of metallic salts generally requires pH control in order to encourage the formation of the hydroxide precipitates. In particular, alum and ferric chloride function most successfully in the pH range from 5 to 7, though this is affected by the particular wastewater. The range of coagulant dosages is very large, due to the wide variety of printing wastewater constituents among mills.

In the research noted above, the optimum dosage of ferric chloride was in the 15 to 25 mg/l range, while Mill W-3 must apply ferric chloride at 600 to 700 mg/l and polymer at 10 to 20 mg/l. These variations point out the need for jar tests to identify an approximate optimum dosage range at a particular mill.

Particle Transport. Particle transport refers to the movement of the colloidal particles to effect interparticle contact. Various theories based on fluid and particle mechanics have been used for qualitative explanations for the transport phenomena observed in coagulation systems. Briefly, the three primary mechanisms for particle transport and contact are:

1. Thermal motion, or Brownian motion, also called perikinetic flocculation;
2. Bulk fluid motion, by stirring, called orthokinetic flocculation;
3. Differential settling (floating), in which contacts occur because particles settle (float) at different rates.

The degree to which particle contact is controlled by each of these mechanisms depends on particle size and the volume fraction of colloidal particles. Generally, perikinetic flocculation is the primary mechanism for particles less than one micron in diameter, and orthokinetic flocculation (stirring) for particles greater than one micron in diameter. Design for orthokinetic flocculation involves the selection of a velocity gradient, reactor configuration, and detention time to produce aggregates for removal by flotation or sedimentation.

Experimental research has shown that the degree of flocculation required for aggregation of printing wastewater colloids is substantially lower than is conventionally required for destabilized suspensions of colloids. The dimensionless product of velocity gradient G and time t is commonly used for flocculation design. The Gt value for printing wastewater was found to be around 5×10^3, while in water treatment practice the Gt values range from 10^4 to 10^5. It has been noted that the aggregates of colloidal particles in the printing wastewater may be fragile and easily ruptured, thus confirming the concept that extended flocculation is unnecessary and potentially harmful in these systems.

At Mill W-3, there are no direct provisions for flocculation. Aggregation is allowed to occur in the dissolved air flotation unit. The performance of this system is discussed further below.

Process Description - Dissolved Air Flotation

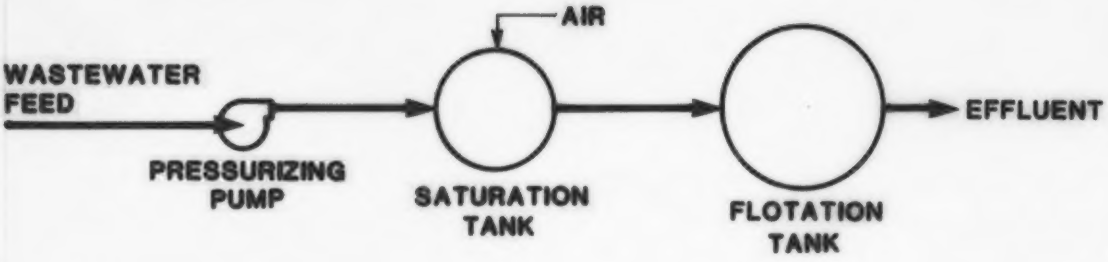
Liquid/solid separation in the treatment of printing wastewater has been successfully achieved by the dissolved air flotation (DAF) process. The principle by which DAF operates is that by reducing pressure on a liquid saturated with air, the dissolved air is released and forms extremely fine bubbles that attach to suspended matter and lift it to the surface in the form of a float. A DAF system can operate in one of the following three modes, which are illustrated in Figure XII-2.

1. Full feed pressurization.
2. Partial feed pressurization.
3. Recycle flow pressurization.

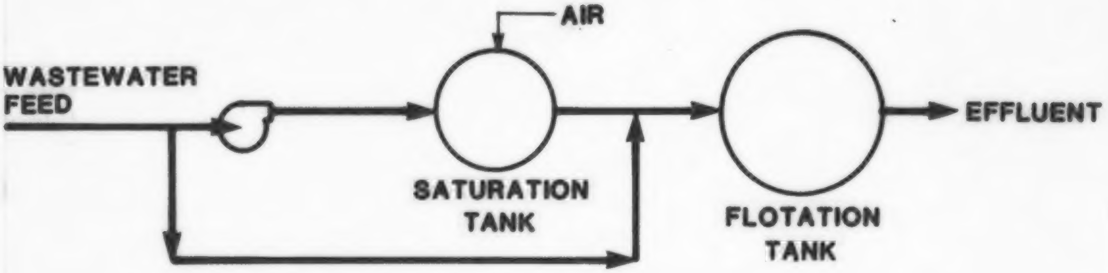
- Full feed pressurization consists of pressurizing the entire wastewater flow in order to maximize the quantity of air introduced and released. This mode has been applied with paper mill wastewater with large quantities of discrete fibers and solids.
- Partial feed pressurization consists of pressurizing about 25 to 50 percent of the wastewater flow, with the remaining portion passing directly to the flotation tank and blending with the pressurized portion. This mode has been successful with oil refinery effluents that contain free oils and other low specific gravity materials.
- Recycle flow pressurization consists of pressurizing a portion of the clarified effluent (about 50 percent of the influent flow rate) and blending this with the raw wastewater in the flotation tank. Typically, the raw wastewater has been treated with coagulants to form a floatable floc, and this system is advantageous in that the floc is not subject to breakup as it would be in full or partial flow pressurization. This mode has been most successful for treatment of printing wastewater. Factors that favor recycle pressurization with printing wastewaters are the need for chemical coagulation, elimination of floc breakup, and the character and quantity of the solids in the wastewater feed that may clog up a pressurizing system.

DAF clarifier units may be circular or rectangular and thus have differing methods of intake, float and bottom sludge removal, and effluent discharge.

FULL FEED PRESSURIZATION


AIR
WASTEWATER FEED
PRESSURIZING PUMP
SATURATION TANK
FLOTATION TANK
EFFLUENT

PARTIAL FEED PRESSURIZATION


AIR
WASTEWATER FEED
SATURATION TANK
FLOTATION TANK
EFFLUENT

RECYCLE PRESSURIZATION

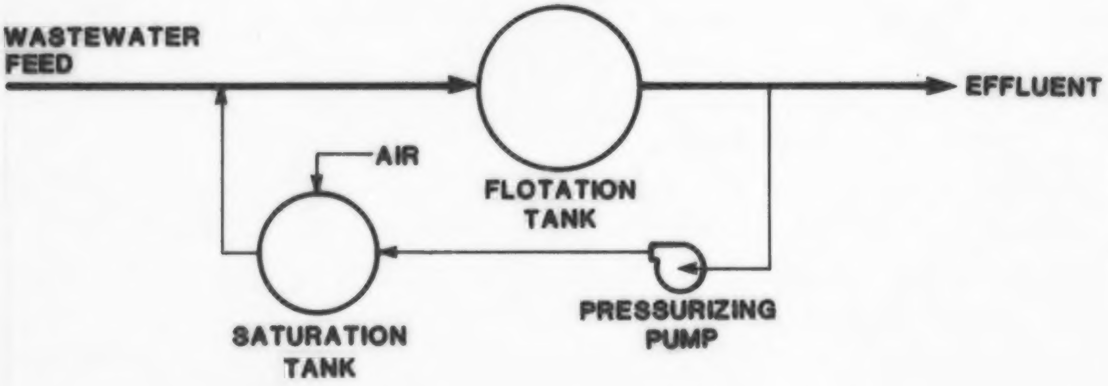

WASTEWATER FEED
EFFLUENT
AIR
FLOTATION TANK
SATURATION TANK
PRESSURIZING PUMP

FIGURE XII-2 OPERATING MODES DISSOLVED AIR FLOTATION

The circular design typically includes a central influent diffuser, radial float skimmers and sludge scrapers on a centrally mounted drive shaft, and a peripheral curtain baffle that acts as an underflow weir for clarified effluent.

The rectangular design typically includes a perforated influent diffuser at one end of the clarifier supplemented by longitudual diffusers on longer units to reduce bubble travel, chain and flight float skimmers, multiple sludge hoppers or chain and flight scrapers for bottom sludge, and a full width underflow effluent baffle.

There are a variety of air saturation systems on the market that act to produce a high degree of air-water contact at a pressure of about 50 psig. Systems may employ impingement baffling, splash plates, recirculation pumps with internal eductors, or mechanical mixers. A reputable manufacturer will recommend an appropriate design.

Process Description - Solvent Recovery

Solvent recovery is performed in three steps: extraction or stripping, condensation, and separation. Extraction is done by passing live steam through the DAF float solids. The solvent evaporates at the elevated temperature creating a solvent/steam vapor. This vapor is then condensed in a water cooled condenser. Immiscible solvents are separated from the water in a decanter and recycled. The water fraction from the decanter can be recycled to the coagulation/flotation treatment system.

Design Criteria

The design of a coagulation/DAF system may vary according to the flow and characteristics of the printing wastewater to be treated. As stated earlier, the chemical types and dosages need to be established by jar and/or pilot testing, and the requirements of a chemical feed system are affected by the results of such testing. The need for rapid mix and flocculation facilities prior to the DAF unit is also affected by the particular wastewater flow and characteristics. Most typical DAF systems with recycle pressurization include provisions for floc formation ahead of the DAF unit, though Mill W-3 does not provide for floc formation prior to the DAF unit. The ultimate decision may be affected by economics and required effluent criteria.

A flow diagram of a typical coagulation/DAF system for printing wastewater is provided in Figure XII-3.

The requirements for DAF design are somewhat more defined than coagulation in that several criteria must be followed to achieve adequate liquid/solid separation. These criteria include solids and hydraulic loading rates, air bubble size, recycle rate, air pressure, and air to solids ratio. The following values are typical for this application.

Solids Loading: 0.2-2 lb/hr/ft^2, higher loading and solids capture with flotation aids such as coagulants/polymers.
Hydraulic Loading: 2-3 gpm/ft^2
Air Bubble Size: 50-100 microns
Recycle Rate: 15-120 percent
Air Pressure: 40-50 psig
Air to Solids Ratio: 0.005-0.06

Typically, the solids loading rate and the hydraulic loading rate are used to size the flotation unit. The air to solids ratio is the critical operating parameter for control.

The air to solids ratio is related to air solubility, operating pressure, and the influent solids concentration by the following equation:

$$\frac{A}{S} = \frac{1.3\ C\ (fP-1)R}{S_a\ Q}$$

C = air solubility, cc/liter (18.7 at 20°C)
f = fraction of air dissolved at pressure P, typically 0.5
P = pressure in atmospheres where = $\frac{p+14.7}{14.7}$

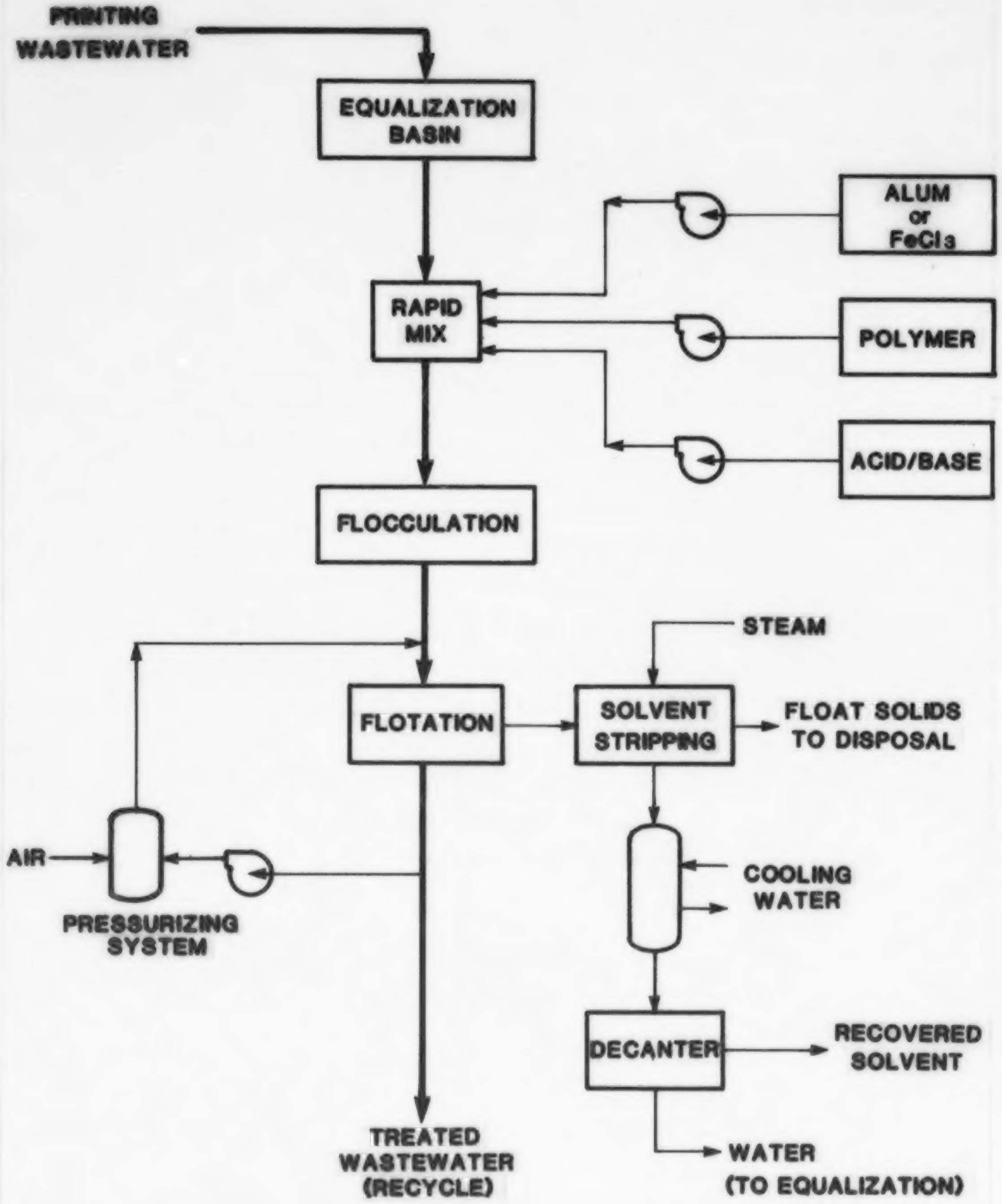

PRINTING WASTEWATER
EQUALIZATION BASIN
ALUM or FeCl3
RAPID MIX
POLYMER
ACID/BASE
FLOCCULATION
STEAM
FLOTATION
SOLVENT STRIPPING
FLOAT SOLIDS TO DISPOSAL
AIR
PRESSURIZING SYSTEM
COOLING WATER
DECANTER
RECOVERED SOLVENT
TREATED WASTEWATER (RECYCLE)
WATER (TO EQUALIZATION)

FIGURE XII-3 COAGULATION-DAF TREATMENT SCHEMATIC

p = gage pressure in psig
S_a = influent solids, mg/l
R = pressurized recycle flow, mgd
Q = total influent flow, mgd

Note that control over the air to solids ratio is exercised by varying the recycle flow.

FACTORS LIMITING TECHNICAL FEASIBILITY

The primary factor affecting the technical feasibility of this recycle technology is the type of printing formulations used in printing. A secondary factor is the ability to segregate the printing wastewater from other mill wastewaters.

Printing Formulations

The printing operation involves the preparation and application of a variety of color formulations that may consist of dyestuffs, rapidogens, pigments, adhesives, and solvents. Although many printing mills rely primarily on pigments, several mills have been identified that rely on dyestuffs such as chrome dyes, vat dyes, fiber reactive dyes, azoic dyes, and disperse dyes. The requirement for successful coagulation/flotation is that the printing wastewater resulting from washing of equipment and floors be a colloidal suspension of the materials mentioned above. This should be the case for pigment printing and for many of the dyestuffs used, but this should be examined when planning a coagulation/flotation system. The actual constituents will affect the type and dosage of coagulant, the flocculation needed, the recycled water quality and the design of the DAF. Therefore, jar and pilot testing is advisable for each mill in planning a coagulation/flotation system.

Segregation of Printing Wastewater

Segregation of the printing wastewater from other types of wastewater, such as preparation or dyeing wastewater, is required. Constituents in other wastewaters may interfere or be incompatible with the coagulation/flotation process and would be undesirable in recycled water.

ECONOMIC ANALYSIS

Capital Cost

Capital costs were compiled in recent studies (References 7 and 8), and the assumptions used for development of these cost curves and equations are reasonable for coagulation/DAF systems in the textile industry. Among the important assumptions are the following:

Hydraulic Loading =	2-3 gpm/sq ft
Recycle Rate =	30 percent
Equalization Time =	4-12 hours
Chemical Feed Capacity =	400-1,000 mg/l alum 10 mg/l polymer
Pumping =	TDH = 30 feet Efficiency = 65%
Holding Tank for Sludge =	2 weeks sludge production volume
Enclosures =	$30/sq ft.

Curves for capital costs of a coagulation/DAF system are shown in Figure XII-4. The total capital cost curve is a summation of the curves for the individual unit operations with the following provisions added:

Unit Operations (installed)	base
Interconnecting Piping, Pumps	8% of base
Site and Electrical Work	25% of base
Contingency	10% of base
Engineering	7% of base

Operating Costs

See Figure XII-5 for a cost curve of operating costs for coagulation/flotation systems. Yearly costs for labor, materials, sludge hauling, and power are based on information compiled in the above mentioned references. Chemical costs are based on dosages of 400 mg/l alum and 10 mg/l polymer.

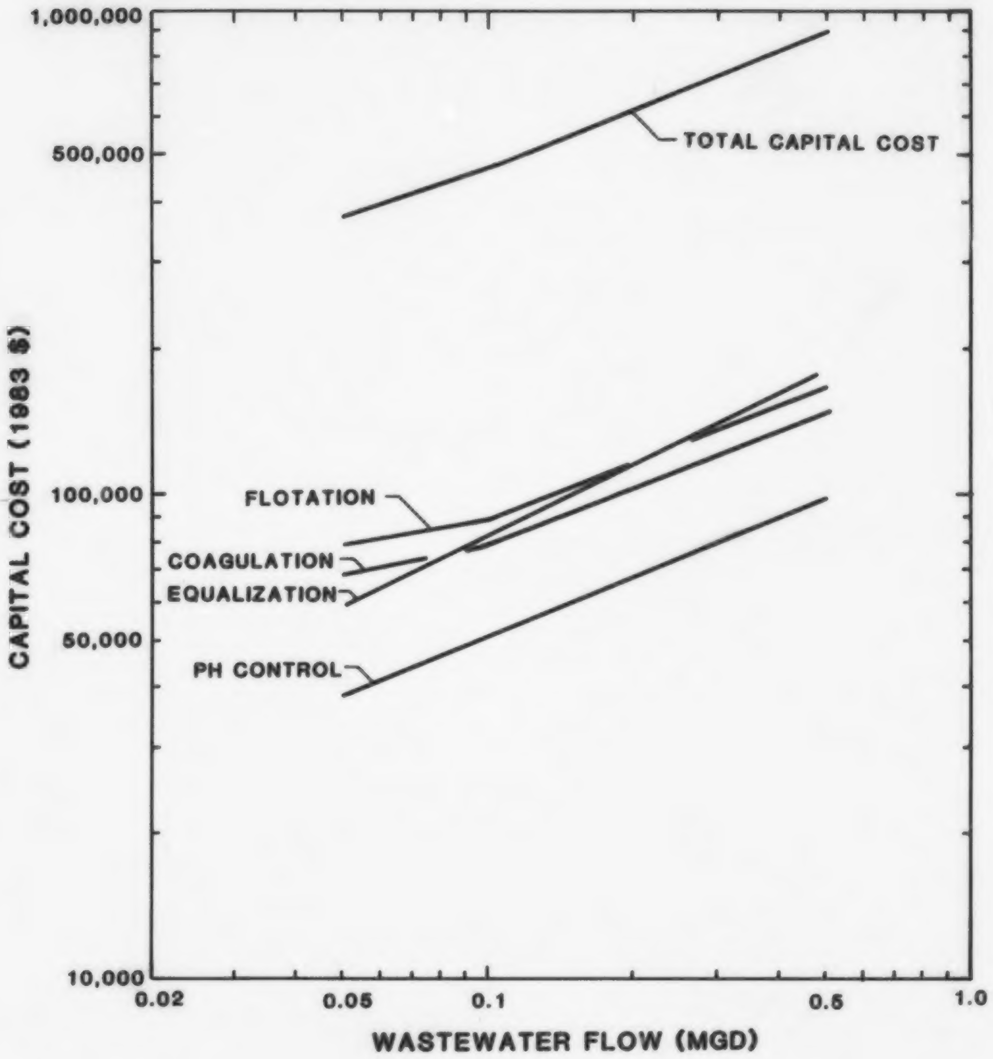


FIGURE XII-4 COAGULATION / DAF CAPITAL COSTS

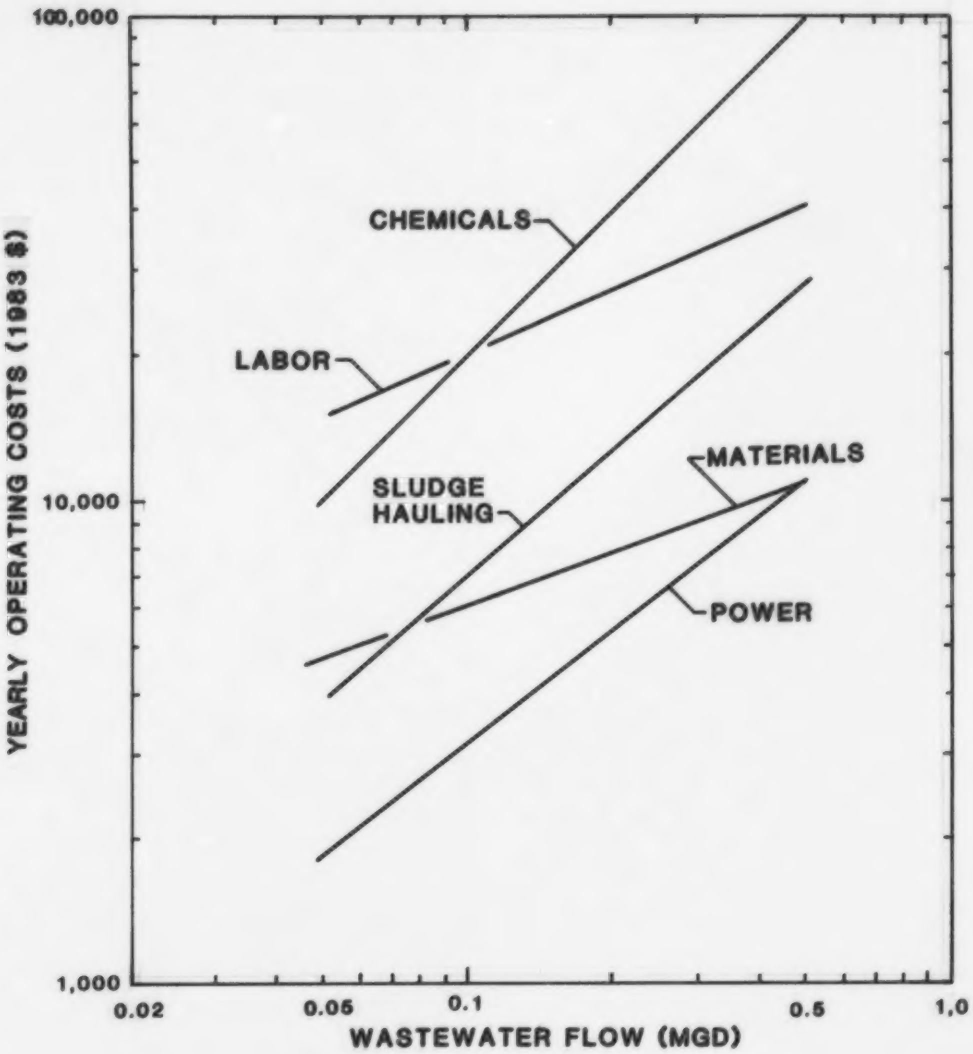


FIGURE XII-5 COAGULATION / DAF O&M COSTS

Baseline Economics

A typical size system of 100,000 gpd was selected to determine the cost effectiveness, or payback period, for this recycle technology. The economic analysis for the baseline case is presented in Table XII-1. Other assumptions used in developing these costs are shown in Table XII-2. A payback period of about ten years (without solvent recovery) is expected for this technology.

Factors Affecting Economics

The factors influencing the economics of coagulation/flotation as a recycle technology include:

- Printing formulations used (coagulant dose, pH adjustment, chemicals, dose, solids loading for DAF sizing).
- Water use (coagulant amount, pH adjustment, chemicals amount, hydraulic loading on DAF).
- Value of recoverable solvents.

Printing Formulations Used. The primary effects of differing printing formulations are on the coagulant type and dosage, and the pH adjustment dosage. As shown in Table XII-1, the chemical costs are a fairly small portion of the operating costs and annual savings, and the payback period is therefore relatively insensitive to changes in the required coagulant dose. For example, reducing the chemical cost by 50 percent only reduces the payback period to 8.5 years. Conversely, increasing the chemical costs by 50 percent increases the payback period to 12.8 years.

The printing formulation can also affect the amounts of BOD, COD, and TSS removed, and the associated reduction in sewer surcharges.

Water Use. The total cost of chemicals and the DAF unit sizing are affected by the flow to be treated. Mills should therefore develop good housekeeping procedures to avoid excessive water use in the printing area. Water and sewer use savings are also affected by the volume of water uses.

TABLE XII-1

BASELINE ECONOMICS
COAGULATION/FLOTATION OF PRINT WASTEWATER

Capital Cost (100,000 gpd system)	$500,000
Yearly O&M Costs	
Labor	$ 20,000
Materials	6,000
Chemicals	20,000
Sludge Hauling	7,000
Power	3,000
	$ 56,000
Yearly Savings	
Water & Sewer (80,000 gpd)	$ 24,000
BOD Surcharge Savings (1,800 lb/day)	81,000
	$105,000
Net Yearly Savings	$ 49,000
Payback Period	10.2 years

TABLE XII-2

BASIS FOR ECONOMIC ANALYSIS COAGULATION/FLOTATION OF PRINT WASTEWATER

Printing Production: 50,000 lb/day, 300 days/year
Print Wastewater Flow: 100,000 gpd

Print Wastewater Solids Concentration: 1,000 mg/l
Print Wastewater Solids Loading: 834 lb/day

Print Wastewater BOD Concentration: 2,500 mg/l
Print Wastewater BOD Loading: 2,100 lb/day

Coagulants: Alum - 400 mg/l (330 lb/day) at $0.15/lb
Polymer - 10 mg/l (8 lb/day) at $1.86/lb

BOD Removal through DAF: 1,800 lbs/day in sludge
Solids Removal through DAF: 834 lb/day from sludge and coagulant addition

Water Savings: $0.50/1,000 gallons
Sewer Use Savings: $0.50/1,000 gallons
BOD Savings: $0.15/lb
Power Cost: $0.05/kwhr
Recycle Percentage: 80% (80,000 gpd)

Value of Recoverable Solvents. The value of recoverable solvents is a potential benefit of this technology, provided that solvents are used as an important constituent of the printing formulation. Mills that rely on pigments for printing generally include solvents in their formulations and recover this by steam stripping of the float solids. The greater the percentage of solvent in the final float solids, the more likely the steam stripping step will be effective and economical. The effect of solvent recovery on the payback period is illustrated in Table XII-3.

CURRENT APPLICATIONS

The following mills were identified as having coagulation/DAF treatment systems for treatment of printing wastewater. As indicated in the tabulation, some incorporate water recycle and/or solvent recovery with their systems.

Company	Water Recycle	Solvent Recovery
Fieldcrest Mills (Stokesdale plant)	Yes	No
Lisbon Textile Prints	Yes	No
Old Deerfield Fabrics	Yes	No
Pervel Industries	No	Yes
William Carter Company	No	Yes
Cranston Print Works (Webster Plant)	No	No
J. P. Stevens (Delta 1)	No	No
Burlington (Brookneal plant)	No	No

The Mill W-3 system has been studied and documented in a Phase II report included in the Appendix. Design and operating data of the coagulation/DAF system are summarized in Table XII-4, and the performance is summarized in Table XII-5. It is evident that solids removal is a problem at this installation. Operating problems that contribute to this are that bottom sludge removal is not performed and the thickness of the float appears to be excessive (three to four feet). This could lead to scouring of solids from the bottom sludge and the

TABLE XII-3

EFFECT OF SOLVENT RECOVERY ON BASELINE ECONOMICS

Capital Cost -	Coag/DAF	$500,000
	Solvent Recovery	80,000
	Total	$580,000
Yearly O&M Cost -	Coag/DAF	$ 56,000
	Solvent Recovery	14,000
	Total	$ 70,000
Yearly Savings -	Coag/DAF	$105,000
	Solvent Recovery	46,000
	Total	$151,000
Net Yearly Savings		$ 81,000
Payback Period		$580,000/$81,000 = 7.2 years

NOTE:

Assumptions used for solvent recovery system:

Feed: 250 gallons per hour, 6 hours per day, 300 days/year
Solvent Constant: 10% Varsol
Solvent Value: $1/gallon
Steam Requirement: 1.26 lb/hour - gallon feed for heating
12.4 lb/hour - gallon produced
Steam Cost: $5/1000 lb
($3.12 per hour of operation)
Other O&M Costs: 10% of capital cost

TABLE XII-4

COAGULATION/DAF
DESIGN AND OPERATING DATA
MILL W-3

Raw Print Wastewater Flow Rate:	200,000 gpd; 125 gpm feed to DAF
Equalization Volume:	0.6 million gallons
Type & Dosage of Coagulants:	600-700 mg/l $FeCl_3$ 20-30 mg/l polymer
Mixing & Flocculation Facilities:	In line and at DAF
pH Control:	Obtained with $FeCl_3$ dose to pH 5-5.5
Type & Size of DAF Unit:	20-foot diameter, Infilco Degremont, Inc.
Typical Solids Loading:	0.1 lb/sq ft/hr
Hydraulic Loading:	0.6 gpm/sq ft
Air to Solids Ratio:	0.02 to 0.04
Air Pressure:	40 psig
Recycle Ratio:	50%

TABLE XII-5

COAGULATION/DAF
PERFORMANCE DATA
MILL W-3

May 1982	BOD mg/l	COD mg/l	TSS mg/l	Turbidity NTU	Color (ADMI units)
Raw Print Wastewater (2 Day Average)	3,000	8,500	600	3,000	18,000
DAF Effluent (2 Days)	620	1,700	300	6	600

lower portions of the float solids layer. Another possible factor is that flocculation is not performed prior to the DAF unit. This affects the DAF performance and the coagulant and polymer dosage. Further details on this example are developed in the Appendix.

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SECTION XIII

DIRECT RECYCLE/REUSE AND WATER REDUCTION MEASURES

INTRODUCTION

This section discusses the direct recycle or reuse of textile wastewater without any need for treatment or reconstitution. In general, direct recycle/reuse is most applicable with relatively clean wastewater streams.

The practice of direct recycle/reuse of water is growing within the textile industry. Direct recycle/reuse accomplishes the objectives of water use savings, wastewater discharge reduction, and energy savings. The list of methods for direct recycle/reuse presented and discussed herein is by no means exhaustive. Mills are continually developing recycle/reuse methods that are compatible with manufacturing processes and convenient in consideration of the physical constraints of the particular mill.

Generally, the economics of this kind of reuse are very favorable, and the typical example presented herein serves to demonstrate the attractiveness of these measures.

ENVIRONMENTAL BENEFITS

Pollutant discharge loads (pounds per day) are generally not affected significantly by direct recycle/reuse measures. However, the reuse of relatively dilute wastewater streams may result in a small increase in the concentrations of pollutants in the total mill effluent due to the reduction in total flow that results from reuse.

Overall wastewater discharge flows and demand for water supply decrease as a result of these recycle/reuse measures with accompanying energy savings in the cases of reuse of hot wastewater streams.

LIST AND DESCRIPTION OF MEASURES

The following discussion is divided into three parts: in-process recycle/reuse measures, cross-process recycle/reuse measures, and water use reduction methods.

In-Process Recycle/Reuse

The use of in-process recycle/reuse measures has increased within the textile industry in the past several years.

The following list includes several of the most popular methods of direct in-process recycle/reuse:

- Countercurrent washing on continuous desize washers, scour washers, bleach washers, mercerizing washers, dye ranges, and soapers.
- Reuse of noncontact cooling water and hot condensate.
- Reuse of extractor water for dyebath makeup in carpet mills.
- Reuse of latex water in backing operations in carpet mills.
- Reuse of final rinsewater in batch dyeing for dyebath makeup.
- Reuse/recycle of water jet weaving wastewater.
- Reuse/recycle of print wastewater for preliminary washing of equipment and floors.
- Exhaust dyeing processes to allow direct reuse.

Countercurrent Washing. This measure is employed frequently on continuous preparation and dye ranges for water and energy savings. Clean water enters at the final wash box and flows counter to the movement of the fabric through the wash boxes. Thus, the cleanest water contacts the cleanest fabric, and the more contaminated washwater contacts the fabric immediately as it (the fabric) enters the actual process. This method of water reuse is opposed to the traditional washing method of supplying clean water at every stage of the washing. Water and energy savings are related to the number of boxes provided with counterflow. Countercurrent washing can be applied at desize washers, scour washers, mercerizing washers, bleach washers, dye ranges, and printhouse soaper ranges.

Countercurrent washing was investigated at several mills during Phase II of this project. It appeared to be feasible at continuous ranges at Mills W-3, W-8, and W-9, and was already in use on some ranges. The mills claimed that fabric quality would suffer if they implemented the measure on all ranges. However, they generally stated that careful evaluation of effects on fabric quality was needed. Generally, the payback would be close to immediate.

Reuse of Noncontact Cooling Water and Hot Condensate. The industry frequently recycles noncontact cooling water to cool process machinery, and also recaptures hot condensate from steam lines for recycle to the boilers or for reuse where hot water is required. This is a popular and fairly straightforward application of methods for water and energy savings. The cooling water can generally be reused through the use of cooling towers to recool the heated water. Cooling tower chemistry is well known and must be applied to avoid deposits or corrosion in the piping system.

Hot condensate from steam lines is readily collected and can be routed to provide makeup water for use of hot water within the plant.

Reuse of Extractor Water and Latex Water in Carpet Mills. These reuse measures are fairly popular in the carpet sector because all of these streams are fairly clean and can be reused at their particular process. For example, the extractor water consists of the water that is mechanically extracted from the carpets after the dye/rinse cycle. This is generally clean enough to be reused as dyebath makeup or for rinsing. Water is involved in the application of latex backings to the carpets, and the excess is generally of adequate quality for reuse at that process. In some cases, the latex solids are also captured through sedimentation for reuse in a more concentrated form, or for final disposal.

Reuse of Final Rinse Water from Dyeing for Dye Bath Makeup. The final rinse in a batch dyeing operation is generally fairly clean. This was shown at several mills in the Phase II investigation and was examined in detail at Mill W-9. It appeared that reuse of this final rinse would be analogous to countercurrent washing on a continuous dye range. The final rinsewater can be reused directly for further rinsing or for makeup of the subsequent dyebath. Several woven fabric and carpet mills are known to use rinse water for dyebath makeup. A payback period of about two years was projected for this measure at Mill W-9.

Recycle/Reuse of Water Jet Weaving Wastewater. Recycle of water jet weaving wastewater was explored at Mill W-4 during Phase II of this project. Analytical data on the wastewater indicated that these waters would be of adequate quality for reuse at the water jet looms or in the desizing/scouring process, provided fabric impurities and oils are removed by in-line filters. A payback period of less than a year was projected for this measure at Mill W-4.

Recycle/Reuse of Print Wastewater for Equipment and Floor Cleaning. This measure was explored at Mill W-3. Most mill personnel agreed that high quality water was not needed during the first stages of equipment and floor cleaning and that a large portion of the wastewater generated during this cleaning could be recycled directly. Perhaps in-line filters would be needed to prevent clogging of hoses or pipes, but this had been demonstrated successfully in Europe and was being incorporated into some automatic cleaning devices designed in Europe.

Exhaust Dyeing Processes. Exhaust dyeing processes use complex control systems to control the dyeing environment such that virtually complete dyestuff exhaustion occurs. In such systems, direct reuse of the dyebath is possible, as opposed to the dyebath analysis/reconstitution steps required before reuse in conventional dyeing. One such example is the Dosacid process (Ciba-Geigy) used for reel dyeing of carpet, wherein pH and temperature control are used to affect exhaustion. Such systems should be considered when replacing old dyeing equipment.

Cross-Process Water Reuse

Cross-process water reuse is less prevalent than in-process reuse measures. Examples of cross-process water reuse include the following:

- Reuse of scouring washwater for desizing.
- Reuse of mercerizing washwater for scouring or desizing.
- Reuse of bleach washwater for scouring or desizing.
- Reuse of print soaper washwater for equipment cleaning or backgrey washing.

Reuse of Scouring Rinses for Desizing. Often, the water quality of the rinsewater from the scouring operation is adequate for reuse in other processes that do not require extremely high water quality. This is particularly true with scouring wastes from synthetic or cotton/synthetic blend fabrics. The desizing process is the prime example of this, as it is the first wet process at a finishing mill and does not require the highest quality water. Scouring rinses may, in certain cases, also be reused for the washing of floors and equipment.

Reuse of Mercerizing Washwater for Scouring or Desizing.

The feasibility of mercerizer washwater reuse was demonstrated to a degree at Mill W-3. The mercerizing washwater is relatively clean and dilute, though it is a very hot and caustic stream which can be used to some advantage in the scouring and desizing operation as long as size recovery is not being practiced. The caustic stream will generally degrade many size compounds to an extent that they cannot be recovered.

Reuse of Bleach Wastewater for Scouring or Desizing. This is very similar to the reuse of mercerizing washwater in that the water is fairly free of suspended solids and other matter and is adequate for processes such as scouring or desizing. Again, the chemistry of the size compounds should be considered. The remaining bleach chemicals may partially oxidize the size compounds and render them unsuitable for recovery.

Reuse of Soaper Wastewater. This measure was explored at Mill W-3, and it appeared that the colored wastewater from the soaping operation would be suitable for reuse at the backgrey washer, which does not require very high quality water, or it could also be used for cleaning floors and equipment in the print and color shop, as high quality water is not needed in this area.

Water Reduction/Housekeeping Measures

Water reduction measures are generally implemented first at a textile mill. This is to minimize the amount of water used and wastewater generated. Water reduction measures often can influence the cost effectiveness of recycle technologies since smaller pumps, piping, and treatment units can be used with the reduced wastewater flow rates.

The following list includes several of the most commonly applicable water reduction/housekeeping measures:

- Maintenance and design of production areas to avoid unnecessary washing.
- Minimization of leaks and spills; containment areas.
- Use of automatic shutoff valves on water supply lines.
- Use of flow indicators and meters.
- Use of liquid level controls.
- Proper use of cooling and heating water through efficient heat exchange methods.
- Hose nozzles and flow reduction devices.
- Employee incentives and education for conservation.
- Solvent cleaning.
- Manufacturing changes - water use practices; decreased needs for washing or equipment cleaning.

Maintenance and Design of Production Areas. Production areas can be designed in such a way as to avoid unnecessary washing of both fabric and unnecessary cleaning of the production areas. Proper maintenance of these areas will assist in decreasing the need for additional washing. Curbs and adequate floor drainage around high water use areas are helpful. Problems were experienced at Mill W-4 when floor drains clogged, leading to a disruptive flood around the preparation area. Though this was cited to be a rare occurrence, it indicated the need for good maintenance.

Minimization of Leaks and Spills. This is similar to the concept above with the addition of thorough maintenance to prevent and repair all leaks and provide containment areas for spillage from machinery. Machinery should also be designed and operated to prevent such spills. The degree of this problem varied widely among the mills investigated in Phase II.

Automatic Shutoff of Water. Often, operators are not as careful as necessary to control the water input to various processes. An automatic shutoff valve after a certain time period or level of water would assist in water reduction. At Mill C-2, it was estimated that a reduction of up to 20 percent in total water use could be achieved with thermally controlled shutoff valves.

Flow Indicators and Meters. Many mills have not been conscious of their water use, and thus cannot measure the benefits of water reduction. They need to install flow indicators and meters at all substantial water use areas in order to obtain a record of the quantities of water typically used and typically required by particular processes. Such records will assist them in further reduction measures. Phase II investigations showed that mills vary widely in their monitoring and recordkeeping practices.

Liquid Level Controls. Liquid level controls are beneficial in keeping the proper amount of water in a process, besides minimizing possible spills or continual overuse of water.

Proper Use of Cooling and Heating Water. Mills have often neglected to provide the most efficient heat exchange methods, thus necessitating excess use of cooling or heating water in various processes. The use of live steam and contact cooling water (overflow rinsing) has been shown to consume large quantities of water. The high capital cost of heat exchange units must, however, be weighed against the benefits of water and energy savings. At Mill C-2, it was shown that these benefits did not provide an acceptable payback period of the capital required to retrofit the dyebecks with cooling coils.

Hose Nozzles and Flow Reduction Devices. Often a simple installation of a nozzle or flow reduction device such as a pressure decreasing device can assist in reducing water use, particularly in cleaning areas where operators are not always conscious of the need for conservation. These measures have been implemented with some success at Mill W-3, though some operators complain and occasionally remove the devices.

Employee Incentives and Education for Conservation. This measure was deemed to be a rather difficult one to implement at many mills due to the history of lack of consciousness among employees. However, such measures must begin and will lead to reduction of water use and wastewater discharge. Mill W-3 cited particular problems with these measures, because water traditionally was considered to be "free" since it came from an on-site pond.

Solvent Cleaning. Judicious use of solvents in the most difficult cleaning situations such as in a print and color shop on some of the equipment can lead to economies in water use. Careful planning of this measure would be necessary to insure savings and avoid environmental deterioration through the possible discharge of excess solvents. Solvent recovery may be considered if substantial volumes are used. Mill W-3 is beginning to consider implementation of such measures for equipment cleaning in their print and color shop.

Manufacturing Changes. Mills may realize savings in water through changes in basic manufacturing processes and more efficient machinery. Mill W-3 presented evidence that screen printing operations require much less cleaning than roller printing operations, thus enabling substantial reduction in water use and wastewater discharge.

Certain types of dye machines, such as continuous ranges and jet dye machines, require lower liquor ratios, and lower water use can thus be achieved with such machinery.

FACTORS LIMITING TECHNICAL FEASIBILITY

The following factors have been identified that may limit the technical feasibility of various direct reuse/recycle and water reduction measures:

- Effects on size recovery practices.
- Effects on quality of fabric and manufacturing processes.
- Clogging problems.
- Physical plant constraints.
- Operator problems.

Effects on Size Recovery Practices

The reuse of bleaching or mercerizing wastewater at a desizing operation is likely to have adverse affects on any attempts to recover size from this operation. The typical oxidizing chemicals in a bleaching operation or the caustic of the mercerizing operation will generally act to degrade the sizes that are normally recoverable, such as PVA. Therefore, such a reuse scheme is not likely to be feasible when size recovery is practiced because of these interference problems.

Effects on Quality of Fabric and Manufacturing Processes

The fact that the quality and quantity of water used in processing is changed by recycle may have effects on the quality of fabric and/or manufacturing processes that are difficult to predict. It is possible that fabrics will be degraded or adversely affected by a certain quality of reused water, and this must be studied carefully during pilot studies of reuse schemes, and must be monitored throughout the process of implementation of a reuse or water reduction scheme. Effects on other downstream manufacturing processes must also be considered and studied carefully.

Clogging Problems

Often, wastewater from typical processes will contain solids and/or oils to a degree that reuse of these wastewaters will cause clogging problems in pipes, hoses, or nozzles. This must be considered, and measures can be taken to prevent such problems including in-line filtration and proper maintenance. Mill W-3 cited filtration practices in Europe that successfully handled these problems.

Physical Plant Constraints

In some mills, there may be difficulty and substantial costs in rerouting pipes and installing storage tanks and pumps due to space constraints at a plant or other piping problems. Although these problems can usually be surmounted through proper engineering, there may be some cases where there is simply not enough room available, or the costs are too high to implement the reuse scheme.

Operator Problems

In some mills, there may be difficulties in training employees and machinery operators to monitor and control water use and/or reuse schemes, due to their traditional ways of performing a certain process. Convincing them to accept and implement new methods can be extremely difficult in some cases and may limit the success of a reuse or reduction scheme. In fact, some employees may go so far as to present an absolute obstacle by stealing various devices such as nozzles or other control devices. This may cause a scheme to be forced to be abandoned. It is hoped that proper training and incentives can be used to discourage and prevent such problems from occurring. Some of these problems were cited particularly by Mill W-3 management during Phase II investigations.

ECONOMIC ANALYSIS

Baseline Economics

To provide an example for demonstrating the economics of this technology, a baseline or model case was examined. The results are presented in Table XIII-1, and the assumptions used in developing costs and benefits are shown in Table XIII-2.

The case involves the reuse of bleach washwater in the scouring process washers at a typical woven fabric finishing mill. The primary costs are related to piping, pumping, and storage, while benefits accrue from energy savings, water use, and wastewater discharge savings.

Factors Affecting Economics

The most important factor affecting the cost effectiveness of this recycle scheme would be the existence of heat exchangers at a particular mill, so that the energy savings actually due to recycle would be decreased substantially. As shown in Table XIII-1, the payback period may increase from about three months to about one year without energy recovery savings.

CURRENT APPLICATIONS

As stated in the introduction, many of the measures are already in use in the industry, and therefore a list of applications is not presented herein. Since these measures are generally economically feasible as shown in the above economic analysis, each mill must weigh the merits of a particular application within the physical and processing constraints at the mill.

TABLE XIII-1

BASELINE ECONOMICS
DIRECT REUSE
(Case: Reuse of Bleach Wastewater at Scouring Operation)

Capital Cost*	
Pump (1 ea)	$ 3,000
Tank/Sump	14,000
Piping (200 LF)	5,000
Electrical (1 lot)	1,000
Capital Cost*	$23,000
Yearly O&M Cost*	$ 1,300
Yearly Savings	
Water & Sewer (75,000 gpd)	$22,500
Energy (62 mm BTU/day)	$74,000
Subtotal	$96,500
Net Yearly Savings, with energy	$95,200
without energy	$21,200

Payback Period, with energy = $23,000/$95,200 = 0.24 years or 3 months

without energy = $23,000/$21,200 = 1.1 years

* Operating cost includes power and routine maintenance.

TABLE XIII-2

BASIS FOR ECONOMIC ANALYSIS
DIRECT REUSE

Bleach Production: 50,000 lb/day, 300 days per year

Scour Production: 100,000 lb/day, 300 days per year

Water Use

Bleach: 1.5 gal/lb
Scour: 1.5 gal/lb

Flow Bleach Wastewater: 75,000 gpd, ignoring losses
Flow Scour Wastewater: 150,000 gpd, ignoring losses

Temperature of Bleach Wastewater: 75°C
Temperature of Scour Wastewater: 75°C
Typical Incoming Water Temperature: 20°C

Water & Sewer Savings: $1.00/1,000 gallons

Energy Savings: $4.00/million BTU

Power Cost: $0.05/kwhr.

Typical Piping Cost: $25/linear foot installed

Typical Storage Cost: $1.00/gallon installed

Typical Pump Installation: $3,000/unit

SECTION XIV
OTHER TECHNOLOGIES

INTRODUCTION

Several other technologies that offer potential for wastewater recycle have been investigated, but are not considered proven in the field. The list of such technologies presented and discussed herein represents a compilation of research efforts to date and demonstrates the need for further work through laboratory and field testing. Technical and economic feasibility of these technologies have not been adequately demonstrated.

ENVIRONMENTAL BENEFITS

The effects of these unproven technologies on pollutant discharge loads have not been investigated to any serious degree, but it is expected that overall discharge flows and water use will be decreased by implementation of these recycle/reuse techniques. Effects on energy and chemical use are uncertain.

LIST AND DISCUSSION OF OTHER TECHNOLOGIES

The following list includes technologies that have been investigated at a laboratory scale, but to date have met with limited or no success in the field:

- Dye recovery by coagulation
- Size recovery by coagulation
- Size recovery by thermal precipitation
- Dye wastewater decolorization by ion exchange resins

Dye Recovery by Coagulation

A schematic of this process is provided in Figure XIV-1. Coagulation and flotation are applied for dyestuff recovery from dyeing wastewater containing oxidized vat or sulfur dyes, or possibly even disperse dyes. Only one mill is known that has used coagulation for dyestuff recovery. This is Canton Textiles in Siluria, Alabama, where indigo dye wastes were treated. Canton developed this process to the extent of obtaining a U.S. Patent 4,092,105 on a method of recovering

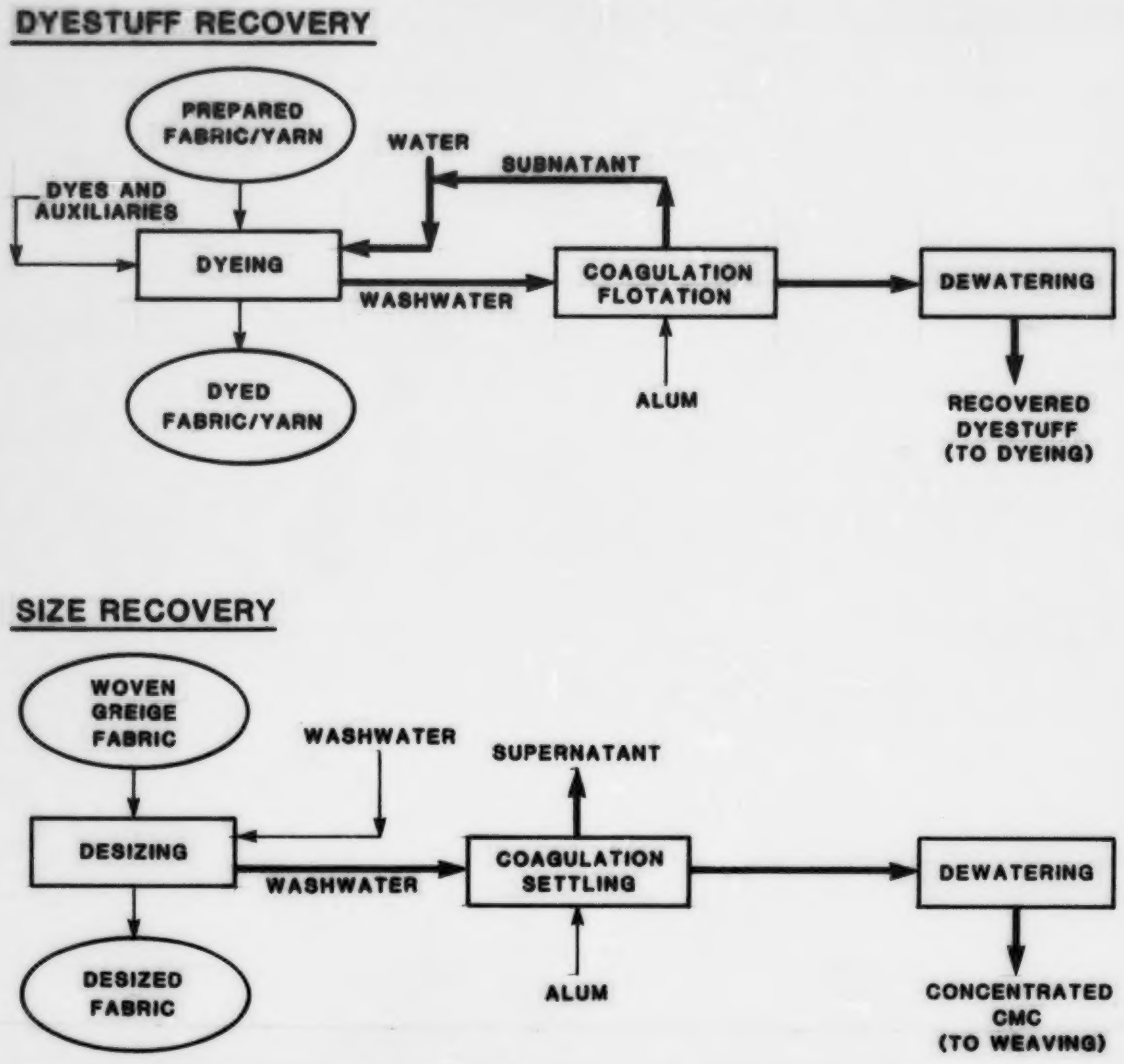

DYESTUFF RECOVERY
PREPARED FABRIC/YARN
WATER
SUBNATANT
DYES AND AUXILIARIES
DYEING
WASHWATER
COAGULATION FLOTATION
DEWATERING
DYED FABRIC/YARN
ALUM
RECOVERED DYESTUFF (TO DYEING)
SIZE RECOVERY
WOVEN GREIGE FABRIC
WASHWATER
SUPERNATANT
DESIZING
WASHWATER
COAGULATION SETTLING
DEWATERING
DESIZED FABRIC
ALUM
CONCENTRATED CMC (TO WEAVING)

FIGURE XIV-1
COAGULATION PROCESS SCHEMATICS

oxidized dye from dye washwater in 1978. Dye recovery and water reuse were demonstrated in bench scale tests and to a limited degree in a full-scale system. The full-scale system consisted of equalization, coagulation of dye solids using alum addition or aluminum ions from an electrolysis unit, dissolved air flotation to remove the dye, filtration of the treated wastewater, and activated sludge treatment. About 50 percent of the filtered water was to be recycled to the mill, and the rest treated by activated sludge and discharged. Float solids (dye) from the dissolved air flotation unit were to be reused in dyeing. However, it appears that dye recovery was never fully demonstrated before the mill closed in 1978, and that treated water recycle was too costly.

Size Recovery by Coagulation

A schematic of this process is also provided in Figure XIV-1. The size compounds carboxymethyl cellulose (CMC) and some modified PVA sizes can be coagulated with salts such as alum and removed from the desizing wastewater. The recovered size is dewatered and reused. Although there are savings in chemical costs for the sizing compounds, the supernatant has not been shown to be reusable due to the buildup of wax, detergent, and spinning oils which all contribute to a large COD concentration. Recovered size has demonstrated a limited capacity for reuse due to the buildup of the coagulation salts, fabric impurities, and oils, and has caused shedding, clinging, and loom stoppage problems after a number of reuse cycles. In addition, the coagulation process has not been successful with commercially produced PVA, necessitating the production of a modified PVA compound suitable for recovery. Another obstacle has been the prevention of hydrolysis or degradation of size during storage of recovered size solutions. This technology has apparently not progressed beyond the laboratory and some small-scale testing in the field. Additional work is needed in defining the capacity for reuse of the recovered size and in defining the potential for water reuse. Ultrafiltration presently appears to be the more favored technology for size recovery.

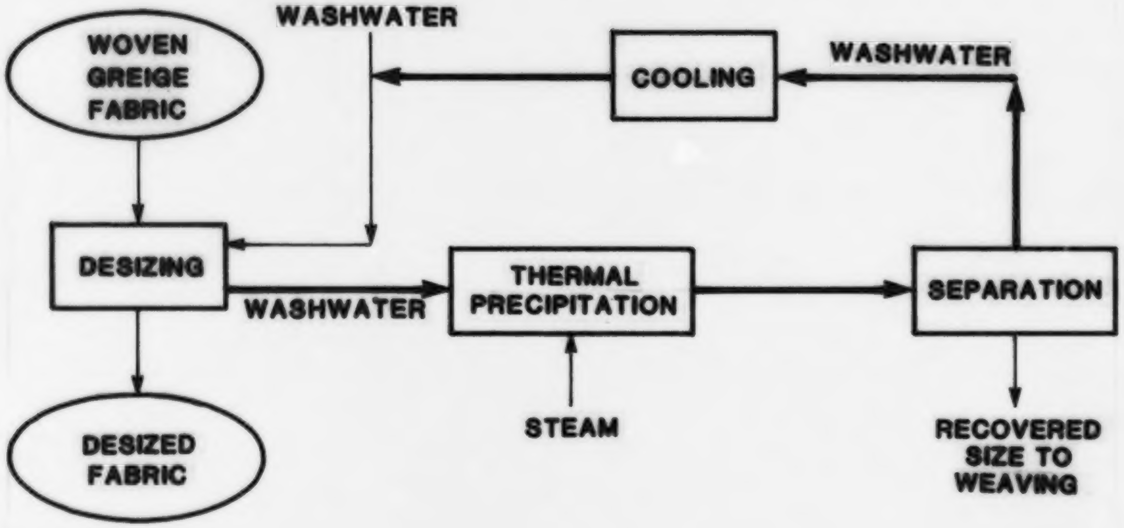
Size Recovery by Thermal Precipitation

Size compounds have been developed that can be precipitated by heating the desize wastewater. The size compounds are hydroxypropyl cellulose (HPC) and hydroxypropyl methyl cellulose (HPMC). These compounds are soluble in cool water but insoluble in warm water. Cool water is used in desizing. The maximum desize system temperature with HPC is about 50°C as compared to 95°C for a conventional (e.g., PVA) system. Although strength and elongation of yarn sized with virgin HPC and reclaimed HPC were not significantly different from those yarns sized with PVA, the abrasion resistance and weaving efficiency of fabrics sized with HPC were lower than that of those sized with PVA at similar add-on levels. Estimates of the capital and operating costs for recovering HPC by thermal precipitation are reported to be lower than those for reclaiming PVA using ultrafiltration. Due to the lower temperatures required, substantial energy savings can also be realized. The reclamation of this size would eliminate most of the BOD typically resulting from the desizing process; however, this technique has not progressed beyond the laboratory. More substantial research is needed to modify the HPC size or develop alternative sizes so that adequate weaving efficiencies can also be achieved. Reuse of the treated desize water must also be demonstrated. Figure XIV-2 shows a process schematic for size recovery with this technology.

Dye Wastewater Decolorization by Exchange Resins

Exchange resins have been investigated on the bench scale for decoloring dye wastewater. The removal mechanisms depends on the nature of the resins and dyes. Removal by chemical adsorption (ionic attraction) occurs between highly cationic or anionic resins and dyes, whereas physical adsorption occurs between more neutral species. Full-scale applications at textile finishing mills are not known at this time, although laboratory testing indicates good color removal. This technique has been demonstrated in the laboratory with direct, acid, basic, vat, and disperse dyes. Disperse dyes caused the most

THERMAL SIZE PRECIPITATION


WOVEN GREIGE FABRIC
WASHWATER
COOLING
WASHWATER
DESIZING
WASHWATER
THERMAL PRECIPITATION
SEPARATION
STEAM
DESIZED FABRIC
RECOVERED SIZE TO WEAVING

EXCHANGE RESIN TREATMENT

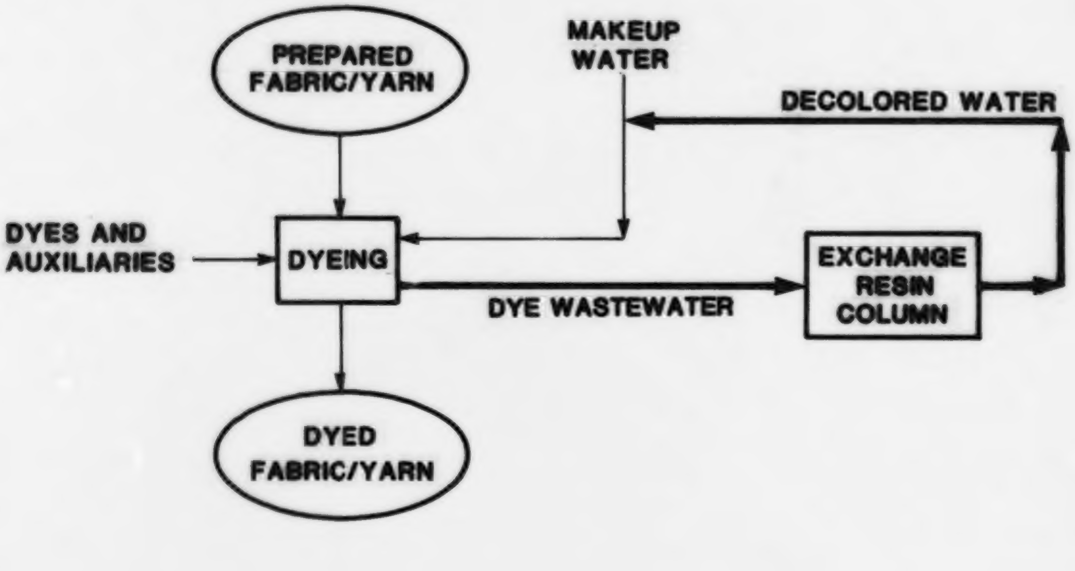

PREPARED FABRIC/YARN
MAKEUP WATER
DECOLORED WATER
DYES AND AUXILIARIES
DYEING
DYE WASTEWATER
EXCHANGE RESIN COLUMN
DYED FABRIC/YARN

FIGURE XIV-2 OTHER RECYCLE / REUSE TECHNOLOGIES

difficulty, and considerable investigation disclosed that complete color removal could be accomplished with a neutral resin column followed by a weak base column. The economical recycling of the decolored wastewater has yet to be demonstrated, however.

One full-scale system was operated by a dye manufacturing plant in the northeastern U.S. This system was installed in 1973 to treat 300,000 gpd of wastewater, reducing the color level from 75,000 to 500 APHA units and COD from 5,280 mg/l to 2,600 mg/l. Two parallel columns of polymeric adsorbent were followed by columns of anion exchange resin. Regeneration of the polymeric adsorbent was by methanol, and regeneration of the anion exchange resins was by caustic, methanol, and sulfuric acid. The methanol was recovered by distillation for reuse, leaving a concentrated water solution of waste dyestuff for incineration. This system treated a much more highly colored solution than textile finishing wastes. However, a more decolored effluent would also be required for reuse in a textile finishing operation.

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